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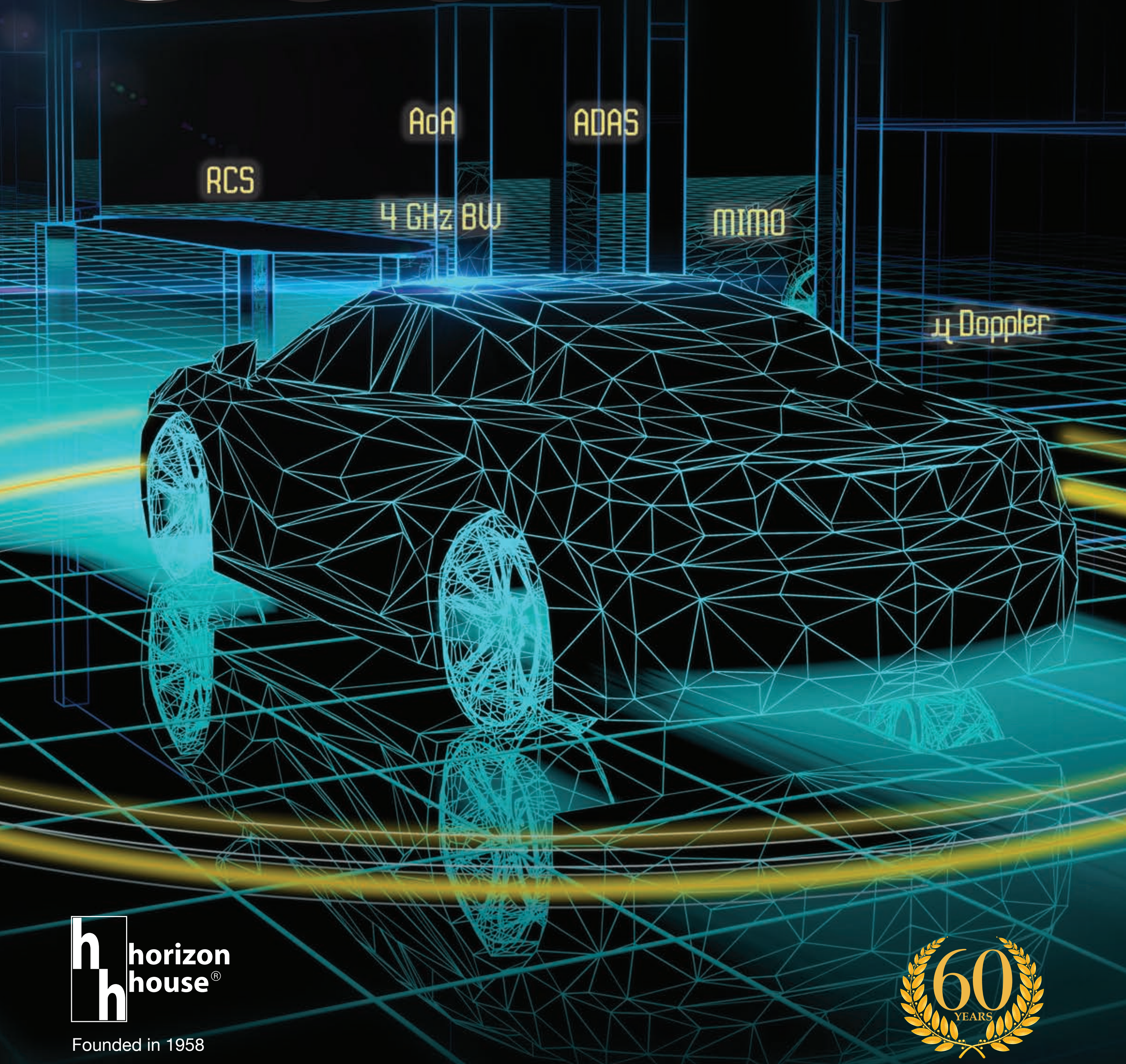
March 2018

Microwave Journal



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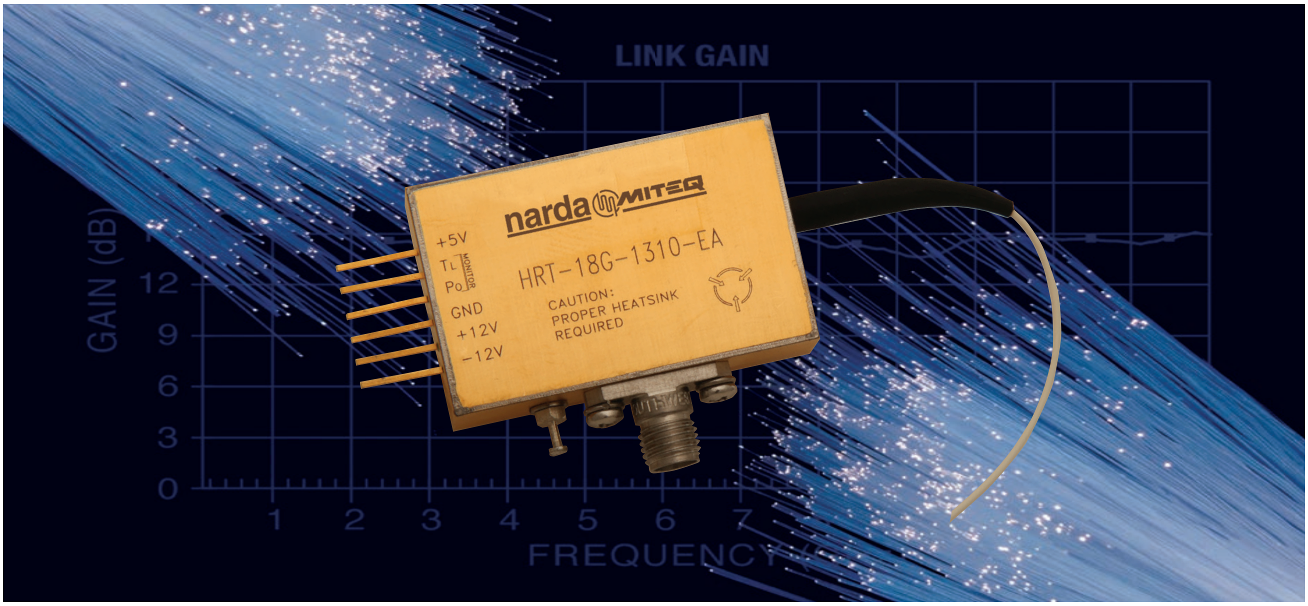

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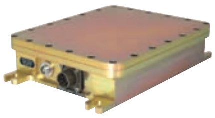

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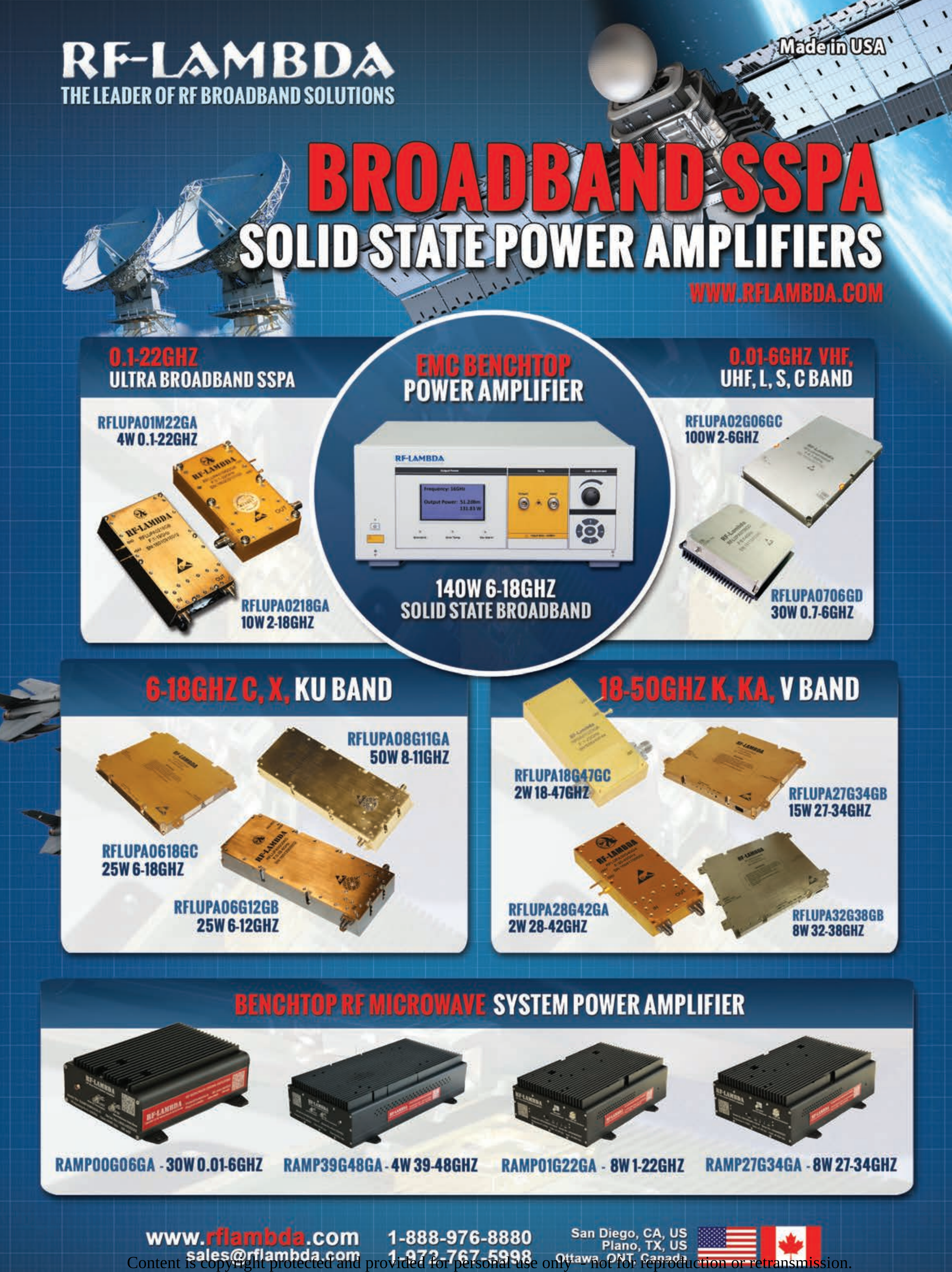

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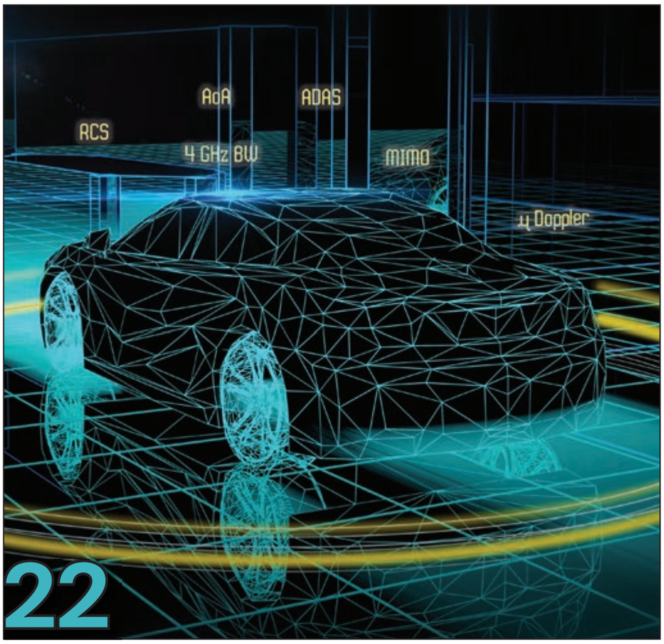

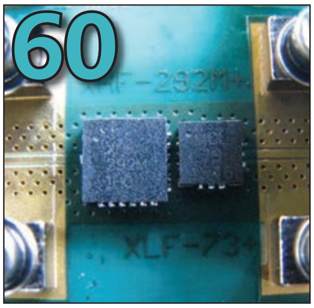

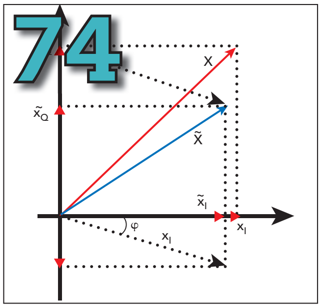

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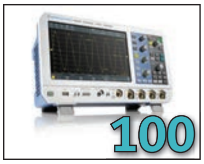

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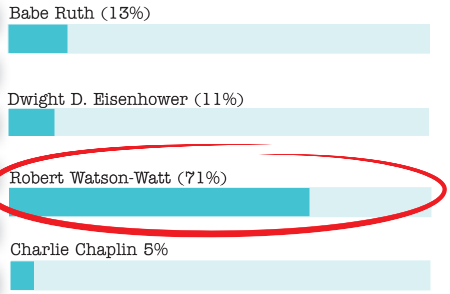
Who invented British radar and oversaw the U.K.'s Chain Home radar during World War II?



Executive Interview

Doug Carlson, VP and General Manager of RF and Microwave at **MACOM**, discusses the recently announced GaN commercialization effort with STMicroelectronics and its impact on the market in this video interview with Frequency Matters.

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9-10
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http://mrw2018.org/

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https://ims2018.org

Sensors Expo 2018
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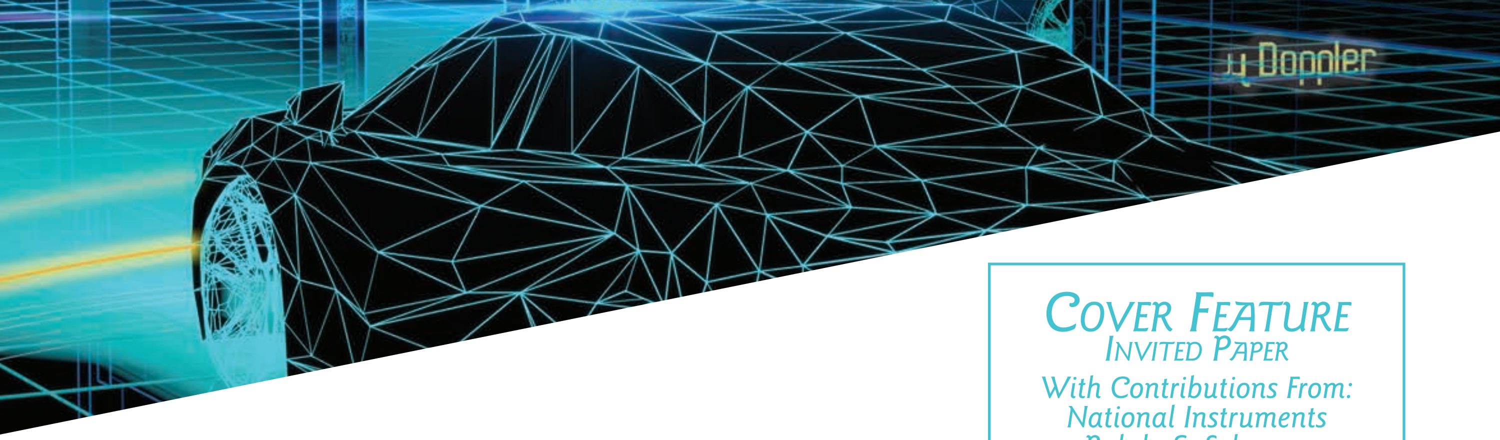

COVER FEATURE
INVITED PAPER
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Editor's Note: Microwave Journal *reached out to three leading test & measurement companies for contributions on the future challenges and solutions for radar sensor testing for automotive safety and autonomous driving applications.*

The Future of Automotive Radar Testing

The Future of Automotive Radar Testing with Modular Solutions

Matt Spexarth
National Instruments
Austin, Texas

Radar has multiple advantages over alternative sensing technologies, securing its role in automotive active safety and autonomous driving well into the future. Radar has the unique abilities to instantaneously detect the velocity of detected objects via the Doppler shift of their radar signatures, and to penetrate inclement weather conditions such as rain, fog and snow. These benefits are driving automakers to adopt radar in increasing numbers. In the U.S., the National Highway Traffic Safety Administration (NHTSA) reached an agreement with 20 automakers, representing more than 99 percent of the U.S. market, to voluntarily equip all production vehicles with Automatic Emergency Braking (AEB) by 2022, a safety feature often enabled by radar.

As vehicles evolve from Advanced Driver Assistance Systems (ADAS) to full autonomous driving, sensors such as radar, LIDAR and cameras are the critical input devices that enable the vehicle to accurately sense the environment around it, providing the context needed for the vehicle to make decisions. Future vehicles may include up to eight radar sensors to provide a full 360° surround view of the car.

Automotive Radar Test Evolution

The growth and advancement in automotive radar has led to several

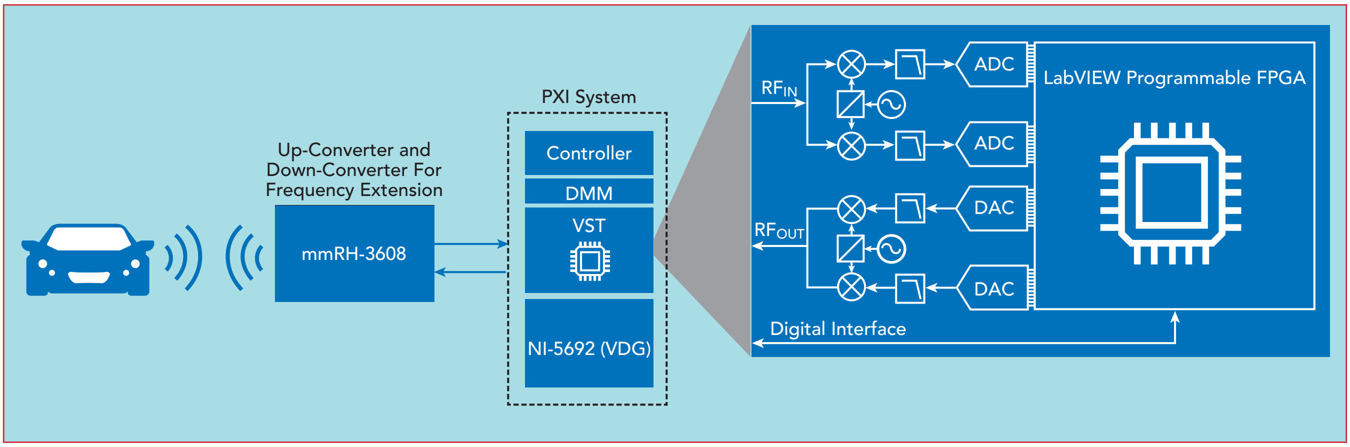
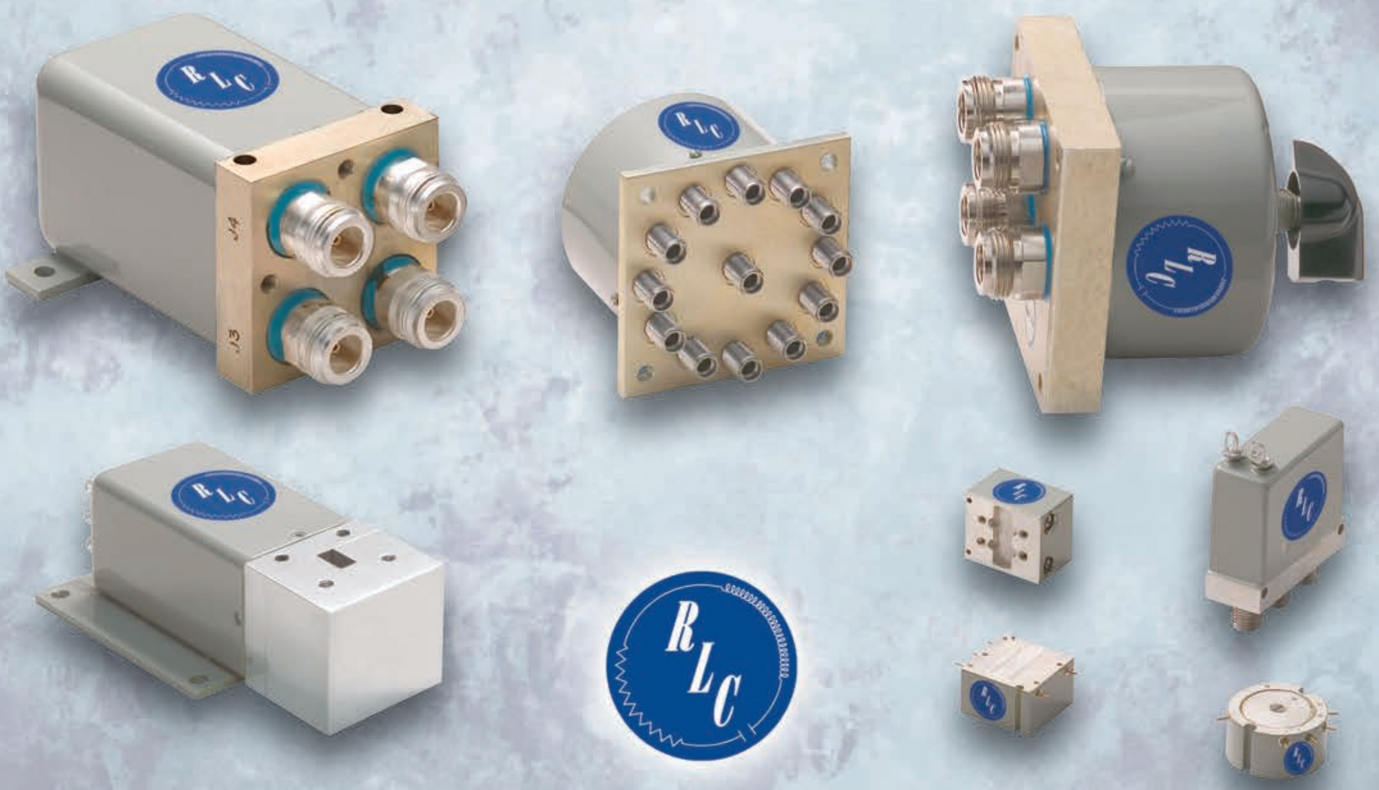


Fig. 1 **Block diagram of the NI Vehicle Radar Test System.**



challenges for the test and validation of radar sensors. The first set of challenges center on meeting the increasing technical requirements for testing modern automotive radar while maintaining or lowering the cost of production test. It is typical for a modern radar sensor to require 1 GHz of bandwidth at 76 to 77 GHz and few companies have the expertise to build test systems in this frequency range. Higher bandwidth sensors provide finer resolution, and radar manufacturers have already demonstrated sensors with higher bandwidths approaching 4 GHz with a 79 GHz center frequency making the testing even more challenging.

While the technology in future radar sensors continues to improve, the time and cost of testing those sensors must be optimized to meet the price and volume requirements to enable the broad adoption of radar. Early radar sensor manufacturers used large anechoic RF chambers and corner reflectors to functionally test and calibrate modules. These chambers were commonly three or five meters long and consumed large amounts of manufacturing floor space. To reduce floor space, radar functional testing evolved to use analog delay lines to emulate long-distance radar obstacles followed by a second test station to perform parametric measurements of the radar.

Radar functional testing has evolved even further with dedicated systems such as the NI Vehicle Radar Test System (VRTS). The VRTS is a hybrid simulator built with a Vector Signal Transceiver (VST) which integrates an instrument-quality Vector Signal Analyzer with a Vector Signal Generator via a high-performance, low-latency FPGA (see ***Figure 1***). This approach can consolidate a radar module production test cell by combining the functional test (object simulation) and the parametric tests into a single tester. The combination reduces manufacturing floor footprint and eliminates the overhead of transferring radar modules between test stations, improving throughput and freeing up space for additional testers.

Beyond the higher frequency and bandwidth requirements of automotive radar testing, the next challenge of testing future radar sensors is the validation of increasingly complex software built into sensors. A radar sensor with 1 GHz or more of bandwidth produces massive amounts of raw data. To avoid overwhelming the communication buses and ECU of the vehicle, radar sensors include a processor to reduce this data into a summarized snapshot. Periodically, the radar transmits a parameterized object table with a summary of all the objects currently tracked by the sensor. Each object includes a range, velocity, radar cross section (RCS), object ID and confidence (a measure of the radar's confidence that an object exists). The radar's software detects these objects and tracks their real-time movements. Algorithms look for inconsistencies such as an obstacle that is moving away from the sensor but has a Doppler signature that indicates the obstacle is approaching.

In the lab, engineers must validate these algorithms and the software that implements them. In-vehicle field testing of these algorithms is critical, but lab testing with a compact radar test system allows software developers to quickly validate software changes immediately. Combined with mechatronics to move the radar simulator antennas, systems like VRTS can generate standardized radar environments to characterize and validate radar sensor software, including simulating corner case scenarios that would be difficult or dangerous to emulate with drive testing. Lab testing with simulators is critical to maintaining the pace of innovation of automotive radar sensor design.

Within the context of the entire ADAS or autonomous driving system, engineers must also consider radar emulation for system validation test. Increasingly, these systems rely on a combination of sensors, including cameras, LIDAR and radar. Validating the overall performance of an ADAS function, like AEB, increasingly utilizes sensor fusion, the combination of two or more sensors to improve the quality or increase the confidence of obstacle detection. For example, if the ADAS radar sensors "sees" an obstacle but the cameras indicate the path is clear,

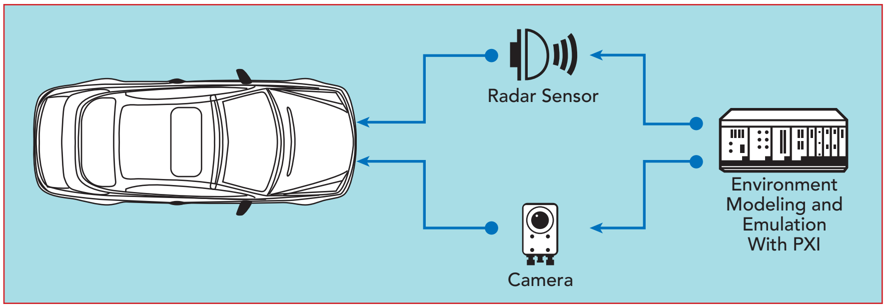


Fig. 2 Validating the software for ADAS and autonomous driving requires synchronized emulation of multiple vehicle sensors so the vehicle "thinks" it is driving in the real world.

then the ECU may disregard the radar obstacle as a ghost or interference.

When testing these functions at the system level, engineers need a test platform that can support a wide set of synchronized sensor simulations to emulate the entire sensed environment around the vehicle. Because systems like VRTS are built on PXI-Express, the standard in modular, automated test equipment, engineers can support additional sensors by adding additional PXI modules, such as the NI FlexRIO, to emulate digital camera inputs in sync with the radar emulation (see ***Figure 2***).

Finally, advanced radar modulation techniques will have an impact on the future of automotive radar testing. Frequency Modulated Continuous Wave (FMCW) radar has been the standard bearer for automotive radar. Radar designers are now looking to use MIMO antennas to augment automotive radar capability to accurately detect obstacle elevation or even provide a raster image similar to a camera. Radar sensor researchers are demonstrating higher performance based on modulation schemes that are similar to those that were commonly used in cellular communication. These schemes can channelize the frequency spectrum allocated to automotive radar, enabling MIMO radars to characterize individual radar reflections between parallel Tx and Rx paths.

This approach promises to improve radar resolution and field of view while enhancing the radar's immunity to interference from other vehicles. In response, radar test systems must also grow in sophistication. Accurately emulating an obstacle at the resolution of these imaging radars may require demodulating individual radar channels, applying the obstacle effects of distance, Doppler and RCS for each Tx channel, modulating each channel per the original scheme and reflecting that obstacle back to the sensor—all at the roundtrip speed of light. These requirements will challenge radar test vendors and suppliers, requiring a high bandwidth, low-latency system architecture with extreme signal processing capabilities.

The Future of Automotive Radar Testing with Radar Echo Generators

Steffen Heuel and Sherif Ahmed
Rohde & Schwarz
Munich, Germany

Automotive radar sensors are safety-relevant and have to be comprehensively tested to ensure reliable functioning. As radar performance, functionality and usage increases, test procedures have to become smarter to eliminate millions of kilometers of drive tests. This article addresses today's radar measurement procedures for functional testing and outlines ideas and essential requirements for future test approaches.

As driving automation moves towards autonomy levels 4 and 5, radars are playing a significant role in complementing other sensor platforms to assure practically all-weather 360° vision capability. In many advanced vehicle designs, several radar units are located around the vehicle to complete the field of


18 DOWNTOWN

view and to allow low-range to high-range coverage up to a few hundred meters. At the same time, the semiconductor industry is progressing rapidly towards multi-static radar operation with antenna arrays consisting of tens of transmit and receive antennas. Some manufacturers are migrating to an all-CMOS design or mixed signal SiGe architecture in order to integrate the digital chain into the radar chip. As a result, radar solutions for ADAS functions and later for autonomous driving have become a cost-effective, irreplaceable solution. Additionally, machine-learning techniques are typically used to facilitate the sensor fusion decision-making process for maneuvering the vehicle in real-time on the street. Several worldwide leaders in the digital processing business are working to achieve highly efficient processors adapted to machine learning requirements, for deep learning algorithms for instance. Some processors are based on a GPU architecture, parallelized CPUs or even on dedicated controller units with direct sensor interfaces.

Automotive Radar Test Challenges

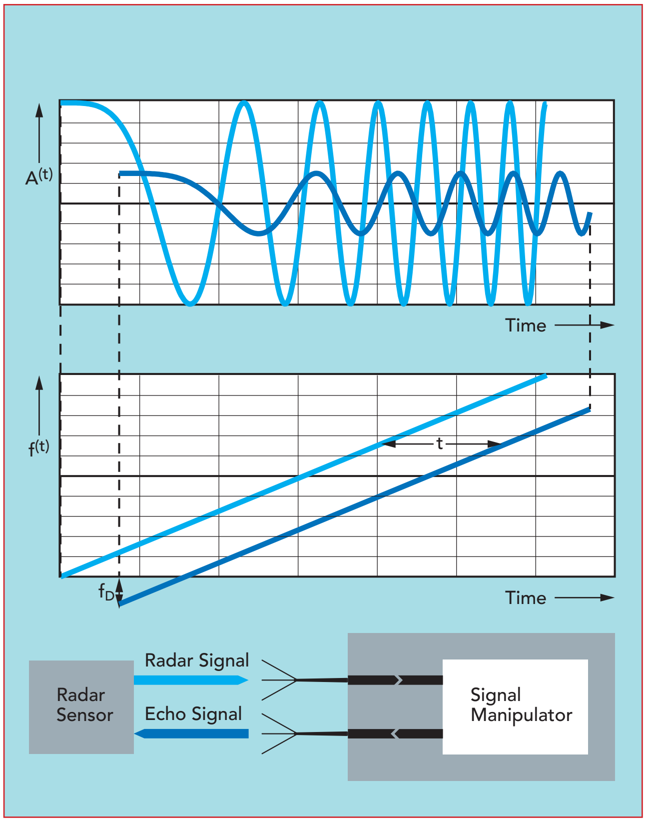
Radar sensors are unique in their ability to measure range, radial velocity, azimuth angle and size of objects by evaluating the echo signals in the observation area in terms of time delay, Doppler shift, angle of arrival and amplitude, respectively. Some modern radar sensors can also estimate the elevation angle and the next generation should provide true measurement of the elevation angle. Determining these parameters simultaneously and in complex multiple object environments, such as intersection scenarios, poses technical challenges for the radar design. To accomplish this, radars need to deliver high-resolution data, a fact that has encouraged many contributors to report on imaging radars or to seek synthetic aperture methods to enhance the radar data. All these requirements place stringent demands on the validation and verification of each radar unit or sensor system to ensure the expected performance.

Due to the increasing complexity and intelligence of radars, it is not sufficient to use direct evaluation of the radar signal quality to judge its performance on the street. Beyond conventional testing of its signal phase noise, Doppler resolution, phase reproducibility, temperature stability, output power, receiver noise figure, chirp slope and linearity, it is becoming necessary to test the function of the complete unit. The influences caused by integrating the radar inside the vehicle itself, e.g. internal reflections of the housing and radome (emblem or bumper) add to this complexity and degrade performance. Consequently, functional testing is becoming a mandatory step for approval by many premium car manufacturers.

Automotive Radar Solutions

Today, the simplest functional test relies on a corner reflector mounted in front of the radar at a specific reference distance. For a stable and reproducible test environment, a large anechoic chamber, such as the R&S ATS1000, is usually needed to suppress any unknown environmental conditions. While this sounds simple, this setup is actually only capable of testing the detection threshold at a given SNR level for a stationary idealistic target. It is not possible to test Doppler resolution and the dynamic behavior of a target, for example to verify tracking and classification processes. It is therefore essential to have a more realistic setup to mimic real-life situations. It is also necessary to include simulated foreign signals from radars of other moving cars to ensure interference mitigation.

Newer on the market are dedicated radar echo generators, such as the R&S AREG100A, that can manipulate the radar-transmitted signal in real-time in order to impose time delay, Doppler shift and attenuation before retransmitting the captured signal back towards the radar under test. A typical implementation would be receiving the radar RF signal and down-converting it to an intermediate frequency, where a time delay (range), radial velocity (Doppler shift) and attenuation (RCS) are introduced. The manipulated signal is then phase coherently up-converted to the RF and retransmitted to the radar under test. The radar



▲ Fig. 3 State-of-the-art radar echo generator principle.

under test receives and processes this modified version of the signal it originally transmitted and reports the detected range, Doppler shift and RCS.

Analog and digital radar echo generators both follow the same concept, but they may manipulate the radar echo signal differently. While analog echo generators use delay lines, e.g., waveguides, coaxial or over fiber optics, in order to delay the signal to a fixed distance, digital solutions have more flexibility in also dynamically changing the range through programmable time delays. A critical parameter in the digital solution is, however, the latency caused by the associated signal processing. Converting the radar waveform from the analog into the digital domain requires at least several digital clock cycles. Since the radar signal propagates at speed of light, each nanosecond of latency would correspond to a distance of approximately 15 cm, which cannot compensated for. While analog radar echo generators are used in verification tests and production lines, digital generators are more often used in research and development and have the potential to test more complex radar scenarios. Single radar echo generators can be used to validate the tracking algorithms for simple radial movements of targets. This would be the case in many Automatic Cruise Control (ACC) scenarios, for instance. To test functions such as lane change assist, the target azimuth angle must be varied and hence the angle of arrival needs to be simulated through the simulator frontend.

Future Testing Methods

Automotive radar development cycles are decreasing due to the tremendous demand resulting from highly automated driving. Radar performance, functionality and applications are all increasing. As the number of applications grows, the scenarios in which the application and ultimately the radar sensor have to be tested increase accordingly.

Today, a million test kilometers have to be driven before a function can claim to be validated. Considering all the new sensors and new cars every year, it is impossible to keep up with drive tests. In addition, decision networks that have been trained with data from "older sensors" may not be valid anymore because the training data and classification algorithms depend on the sensor itself. This means, a new sensor requires a new training and test data set, which means another million test kilometers. Since future production cars will be highly automated and fully autonomous, we need to find ways to reduce the required kilometers of drive tests. For legacy cars, vehicle in the loop (VeHIL) test rigs are available. But

for newer production cars that rely on radar sensor information, these test rigs have to be updated with additional test equipment.

In many cases, a car on a test rig will not even accelerate before the radar is manipulated. Radar echo generators and simulation of radar sensor echoes via electronic control unit (ECU) interfaces are a good starting point. While software simulation of radar sensors can be comprehensive and fulfill many demands, it does not really replicate the radar's real-life behavior. Radar echo generators, on the other hand, test the radar and simulate range, Doppler and azimuth. At the present time, however, radar echo generators are not able to generate realistic scenarios for many azimuth and elevation angles that a sensor detects in a normal environment. This is because radar echo generators have a limited number of transmit and receive antennas and therefore cannot simulate a varying angular direction for the radar sensor under test (see ***Figure 3***). As already indicated, this is sufficient for simple functional tests or performance tests such as accuracy, detection threshold or resolution, but definitely not for functional testing of advanced driver assist systems and autonomous vehicles.

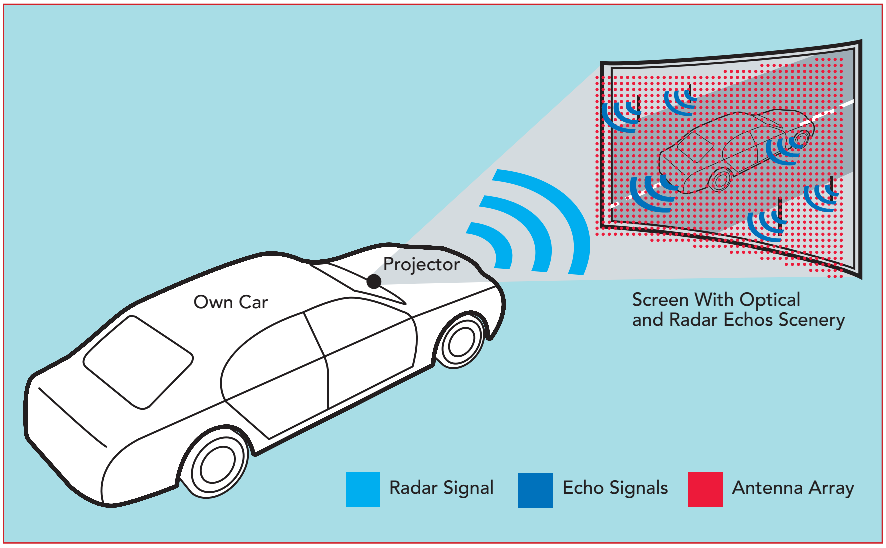


Fig. 4 **Future radar echo generator principle.**

A radar echo generator may require hundreds of receivers and emitters to capture, manipulate and retransmit echo signals that are as realistic as typical radar echo signatures. Besides the angular limitation, today's radar echo generators also cannot simulate distributed targets (known as cloud targets). Pedestrians do not appear as a single reflection. They have multiple reflection points and the torso, legs and arms have different velocities. Vehicles do not appear as a single scatter point, but have distributed scatter points in range and azimuth with mainly a single Doppler component. All these requirements have to be taken into account when generating the realistic radar echo signals needed to test tracking, classification and decision processes from a scenario and functional point of view.

Figure 4 shows a concept where a radar echo generator consisting of an antenna array is mounted behind a screen. The screen shows a driving scenario, for example a highway scenario, for the camera sensor that supports the driver assist system.

A completely electronically controllable antenna array with thousands of emitters with a digital processing backend could be used to stimulate a radar sensor with complex targets and their maneuvers. The sensor is positioned in front of the measurement system, which receives the radar transmit signal, manipulates the range, Doppler, RCS in real-time and routes the echo signals to a specific antenna inside the antenna array, resulting in an azimuth

and elevation angle for the radar under test. The beauty of this modular approach is that the reflection of the echo signal would be just like in real life. Large antenna arrays in this frequency range exist and can be used for radar testing, but there is presently no commercial radar echo generation solution available that can generate complex point cloud targets from such an antenna array.

Testing autonomous vehicles with their increasing amount of radar sensors, different operational modes, and sensor functionalities, will be more complex in future. To address these challenges, radar echo generators with single transmit and receive antennas are a good approach, but do not completely fulfill the requirements of future radar sensors and scenario testing. An antenna array in combination with a digital radar echo generator would have the capabilities to address the needs of testing radar sensors more realistically. Since research and development on autonomous cars, the scenarios to be tested, radar sensors and their fusion with other sensors such as laser scanners and cameras continues, OEMs, Tier 1's and test and measurement manufacturers have to work hand-in-hand to provide solutions for the growing demands.

The Future of Automotive Radar Testing with Integrated Simulation Software

Jungik Suh
Keysight Technologies
Santa Rosa, Calif.

Radar has played important roles in the automotive industry for many years, specifically for safety (emergency automatic braking system, blind spot detection and rear collision protection) and convenience (adaptive cruise control, stop-and-go and parking assistance). Radar's role has since expanded to a higher level of contribution in the industry for autonomous driving systems.

To achieve flawless operation in critical missions, pressure on automotive radar tests has become higher. More complicated design and test solutions are required to characterize higher frequencies (77 and 79 GHz), wider bandwidths (2, 4 GHz and beyond), multi-antennas and other automotive radar technologies like micro-Doppler. Higher performance measurement equipment such as better Displayed Average Noise Level (DANL), higher dynamic range, frequencies up over 100 GHz, 4 GHz and wider bandwidth signal analysis, are helping automotive radar developers achieve their test goals. However, advanced and future automotive radar tests require integrated simulation and measurement solutions with powerful simulation software and high performance test equipment to solve more complicated test challenges.

Integrated Simulation and Measurement Solutions

Demand for high frequencies and wider bandwidths for automotive radar has continuously grown with the need for better target range resolutions and smaller, lighter sensors. To validate these high frequency and wide bandwidth automotive radar signals, test and measurement companies have introduced high performance signal analysis and generation solutions, such as the Keysight N9041B UXA signal analyzer.

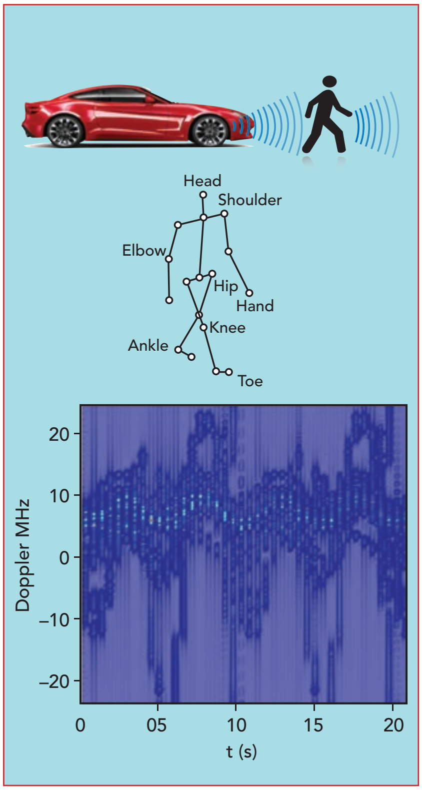
In addition to the need for high performance measurement equipment with wide bandwidth mmWave signal characterization capabilities, advanced automotive radar tests require more integrated solutions based on simulation and measurement for faster and more accurate development cycles. For example, multi-scatter target parameterized simulation models are available with the advanced automotive radar simulation software, such as Keysight W1908 SystemVue Automotive Radar Library, to realize and visualize the micro-Doppler effects on the target.

Automotive radar is a critical element of the autonomous driving system—by detecting traffic components around the vehicle, it should

also be capable of distinguishing components of urban environments under a complicated scenario with a density of busy traffic from multiple components, including many pedestrians around the environment. Automotive radar with micro-Doppler can separate pedestrians from moving vehicles because when pedestrians are walking or running, they naturally move arms, elbows, hands, knees, toes and other parts of their bodies, which generate different micro-Doppler shifts from their torso. Advanced automotive radar developers will need to simulate and test micro-Doppler to validate their radar to detect slow-moving pedestrians. Considering the large number of complicated test scenarios with automotive radar, micro-Doppler target model simulation and test are quite critical regarding the impact to human lives.

In ***Figure 5***, a walking pedestrian scenario is shown. New software solutions can visualize reflections such as the micro-Doppler signature in the spectrum with different scenarios, such as walking pedestrian, running pedestrian, moving car or even customized trajectory for special scenarios. It also provides >10 scatters for a walking passenger scenario to thoroughly model the micro-Doppler effect with the automotive radar.

After the simulation is complete, developers can generate waveforms and scenarios using test equipment, such as Arbitrary Waveform Generators (AWG), to directly create the signals from simulations as well as post-processed signals captured from test equipment, which accelerate the product development cycle from simulation to prototyping. As technologies used for automotive radar are becoming more complicated, this collaborative simulation software and measurement equipment solution will solve advanced and future radar tests like micro-Doppler.



▲ Fig. 5 Walking passenger trajectory example with visualized micro-Doppler effect in SystemVue Automotive Radar Library.

Fig. 6 Comparison of 1 GHz (a) and 4 GHz (b) bandwidth radar tests—wider bandwidth test can validate two separate, closely spaced signals.

Why Arbitrary Waveform Generators?

As wider bandwidth testing is critical for advanced and future automotive radar, AWGs now play multiple roles in the testing process. AWGs can generate extremely wide modulation bandwidth, for example, from DC to 32 GHz, which enables engineers to discern targets even if they are close together. Since waveform generation in AWGs is digital, they can generate multiple signals—at different frequencies and at the same time (see ***Figure 6***). This allows a realistic simulation of radar scenarios with multiple emitters transmitting simultaneously. Also, AWGs typically offer multiple, synchronous channels, allowing engineers to test multi-channel radar receivers and simulate, for example, a certain angle-of-arrival (AOA). With the RF signal coming straight from the DAC, the phase from pulse to pulse and channel to channel is 100 percent repeatable, which is important for consistent test results. Another benefit is the flexibility in terms of modulation formats—this is ideal to develop new modulation schemes that are more tolerant to interference. In addition, AWGs can generate the simulated signals directly downloaded from simulation software tools like SystemVue.

Future automotive radar tests require both software-based simulation and high-performance measurement equipment to improve radar performance and accuracy and reduce development time and cost. Advanced software is now available to help engineers create their own simulations with various example workspaces based on essential automotive radar scenarios: micro-Doppler, multiple target detection, antenna 3D scan, radar scene simulations with ground clutter (asphalt, cement or mud), pedestrian and multi-scatter target, direction of angle (DOA) degree calculation along with phase comparison, propagation loss under rain and MIMO radar.■

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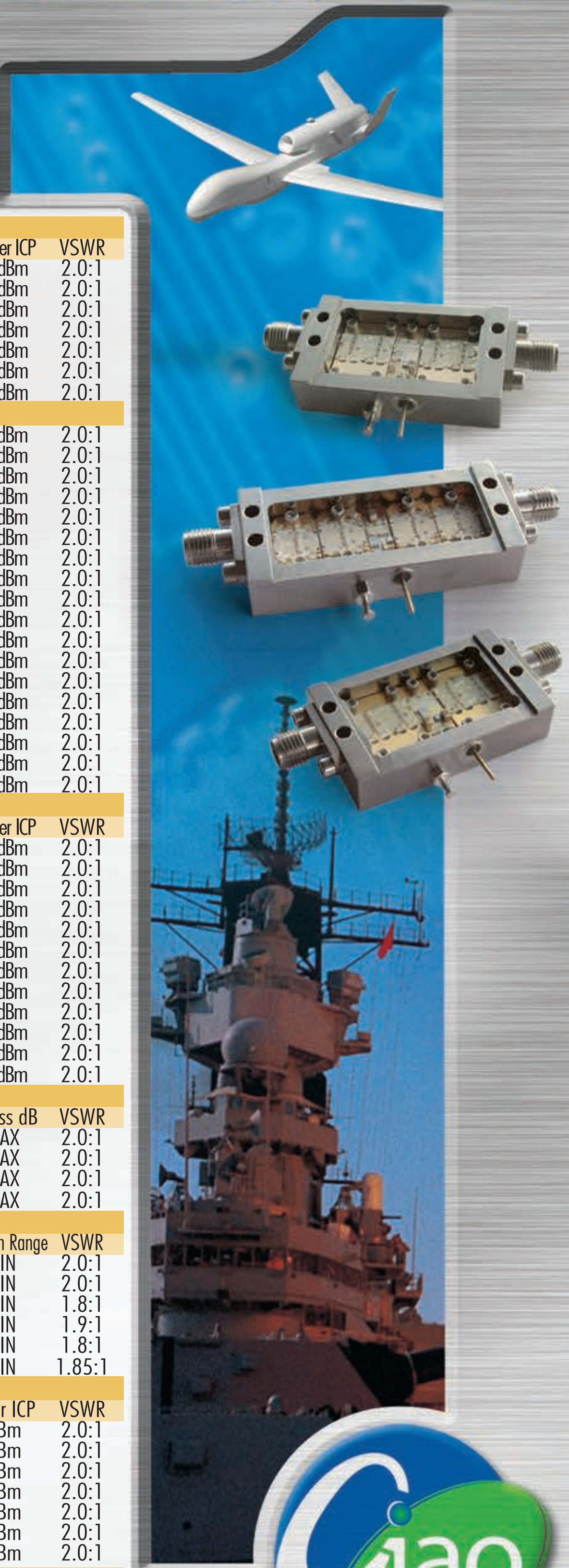

OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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DefenseNews
Cliff Drubin, Associate Technical Editor

What Can 5G Learn from the Military Communications Market?

Software defined architecture, solid-state technology, radio-satellite communications-wireless network integration will underpin growth for military communications systems and the associated component and semiconductor demand. Strategy Analytics ADS forecasts spending on global military communications systems and services will grow to over $36.7 billion in 2026, a CAGR of 3.5 percent.

Military communications operate under an umbrella of heterogeneous networks that enable the provision of interoperable voice, video and data services across a global environment, segmented according to security policies, transmission requirements and the individual needs of the end user. In terms of the networked battlespace, this can be summarized as:

- Upper level networking, consisting of infrastructure and networking components;
- Mid-level networking providing high capacity backhaul;
- Support to the tactical edge for end-users and sensors.

"In a similar fashion, 5G serves as an aggregator technology that will encompass a range of network types and technologies to serve both traditional voice, video and data requirements to the end-user, as well as opening up capabilities to enable connectivity across devices including vehicles, machines, sensors and devices," notes Eric Higham, North American director for ADS.

Phased arrays, beamforming, mmWave frequencies, SATCOM, GaN, duplex communications and shared spectrum access are among the crossover technologies that will become common across both commercial and military communications.

"Communicating voice, data and video simultaneously and securely over wider and higher bandwidths in an increasingly complex spectrum environment will underpin trends for military communications system design and associated component demand," observed Asif Anwar, ADS director.

DARPA Seeks to Improve Military Communications with MIDAS Program

To expand the use of mmWave phased-arrays and make them broadly applicable across DoD systems, many technical challenges must be addressed, including wideband frequency coverage, precision beam pointing, user discover and mesh networking. The use of multi-beam phased arrays as well as advances in digital radio and mmWave technology have propelled technology to the current state, and now there is a paradigm shift on the horizon as mmWave phased-arrays are poised to change communication and networked mobile platforms.

Commercial applications are primarily solving the "last mile" problem, where consumers are demanding more bandwidth for high-throughput applications over relatively short ranges at predetermined frequencies and with minimal obstacles to user discovery. DoD platforms on the other hand create far more complex communications environments. Often separated by tens or even hundreds of nautical miles, today's military platforms are moving in three dimensions with unknown orientations. This environment is creating unique beamforming challenges that cannot easily be solved by applying current communications approaches.

"Imagine two aircraft both traveling at high speed and moving relative to one another," said DARPA Program Manager Timothy Hancock. "They have to find each other in space to communicate with directional antenna beams, creating a very difficult challenge that can't be solved with the phased-array solutions emerging in the commercial marketplace."

To address these challenges, DARPA is launching the Millimeter Wave Digital Arrays (MIDAS) program. The program aims to develop element-level digital phased-array technology that will enable next generation DoD mmWave systems. To help solve the adaptive beamforming problem and ensure wide application of the resulting solutions, MIDAS seeks to create a common digital array tile that will enable multi-beam directional communications. Research efforts will focus on reducing the size and power of digital mmWave transceivers, enabling phased-array technology for mobile platforms and elevating mobile communications to the less crowded mmWave frequencies.

Advances in element-level digital beamforming in phased-array designs are enabling new multi-beam communications schemes—or the use of several beams receiving and transmitting in multiple directions simultaneously—to help significantly reduce node discovery time and improve network throughput. "While critical to the next generation of phased-arrays, today's digital beamforming is limited to lower frequencies, making the resulting arrays too large for use on small mobile platforms," said Hancock. To reduce the size of the arrays, advances in mmWave technology will help push the frequency of operation to higher bands, bringing the capabilities of directional antennas to small mobile platforms.

To accomplish its goals, MIDAS is focused on two key technical areas. The first is the development of the Si chips to form the core transceiver for the array tile. The second is the development of wide-band antennas, transmit/receive components and the overall integration of the system that will enable the technology to be used across multiple applications, including line-

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of-sight communications between tactical platforms as well as current and emerging SATCOM.

GA-ASI Demos SATCOM LRE for MQ-9B

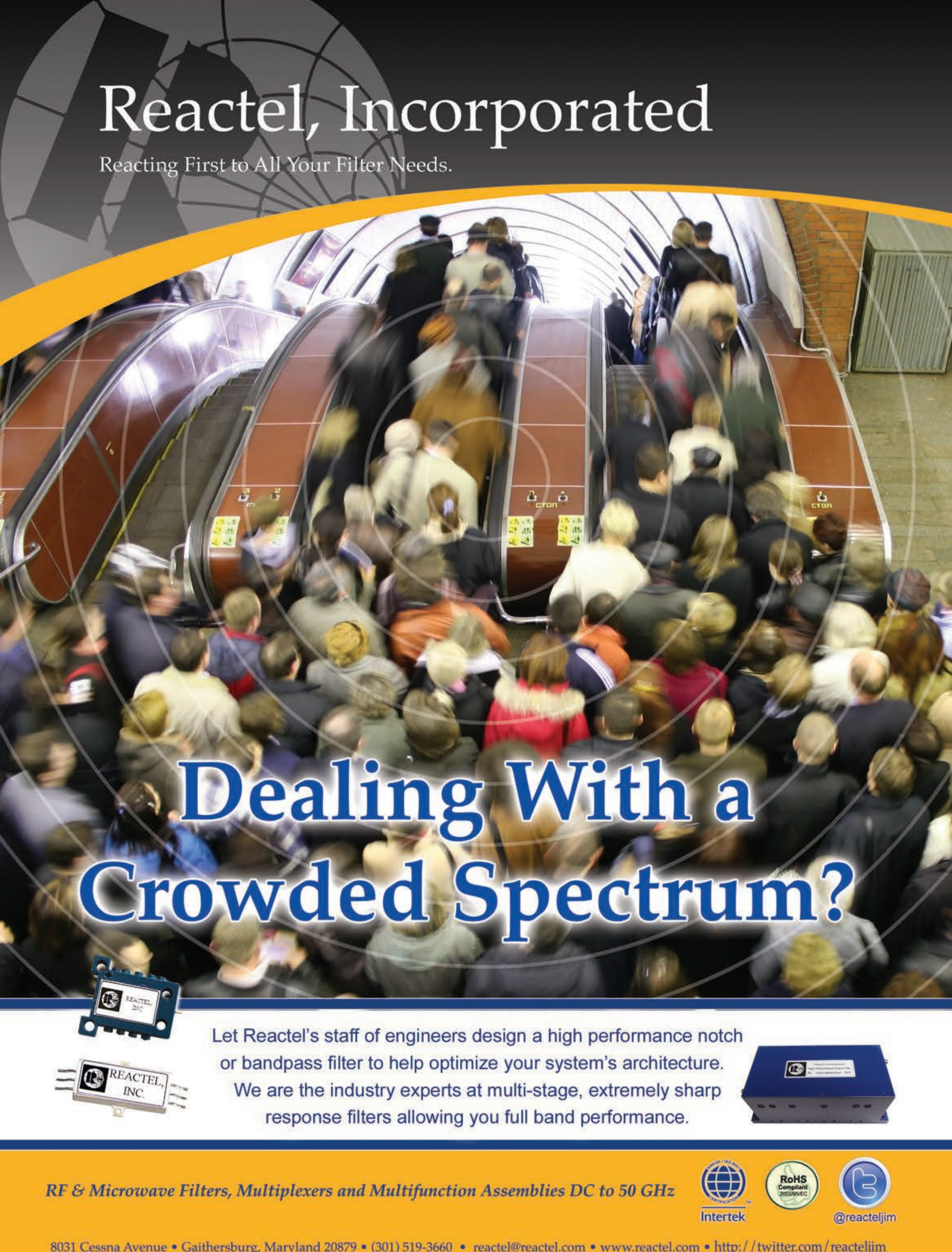
General Atomics Aeronautical Systems Inc. (GA-ASI) successfully demonstrated its latest Automatic Takeoff and Landing Capability (ATLC) using a SATCOM data link for its MQ-9B SkyGuardian™/SeaGuardian Remotely Piloted Aircraft (RPA). The demonstration also included the first SATCOM taxi of the MQ-9B. This capability eliminates the need for a ground control station (GCS) and pilot/flight crew to be located at the aircraft's base which will drastically reduce airlift requirements when the RPA is "forward deployed."

The SATCOM-only Launch and Recovery Element (LRE) operations capped a year for MQ-9B development, which included an endurance flight of more than 48 hours in May 2017 and the first FAA-approved flight for a RPA in non-segregated airspace in August 2017. The MQ-9B will become the first RPA with SATCOM LRE functions when the MQ-9B PROTECTOR is delivered to the U.K.'s Royal Air Force in the early 2020s.

The demonstrations were conducted using GA-ASI's capital MQ-9B SkyGuardian. The supervisory crew and GCS operated out of the company's Gray Butte Flight Operations Center near Palmdale, Calif., and the aircraft was flown out of Laguna Army Airfield near Yuma, Ariz. Using only a SATCOM datalink, the team successfully taxied the aircraft and initiated six auto takeoff and landing events.

SATCOM ATLC enables taxi, launch and recovery operations from anywhere in the world and reduces required aircrew manpower and LRE footprints. With trained RPA aircrew only required at the mission control element GCS location, the overall operating cost of the RPA is reduced. It also enables rapid self-deployment of aircraft to any global runway with a GPS surveyed file.

MQ-9 (Source: U.S.A.F. Photo)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UN Broadband Commission Sets Global Broadband Targets

Fifty percent of the world's population is expected to be connected to the Internet by the end of 2019. This leaves the other half—an estimated 3.8 billion people—unconnected and unable to benefit from key social and economic resources in an expanding digital world. In response, the United Nations' Broadband Commission for Sustainable Development has set seven ambitious, yet achievable, 2025 targets in support of "Connecting the Other Half" of the world's population.

The 2025 targets specifically seek to expand broadband infrastructure and Internet access and use by populations around the world, in support of achievement of the Sustainable Development Goals established by the UN and the international community in September 2015—and in doing so, to improve livelihoods and economies.

> "...an expanding digital world..."

The seven targets aim that by 2025: all countries should have a funded national broadband plan or strategy, or include broadband in their universal access and services definition; entry-level broadband services should be made affordable in developing countries, at less than 2 percent of monthly gross national income per capita; broadband/Internet user penetration should reach 75 percent worldwide, 65 percent in developing countries and 35 percent in least developed countries; 60 percent of youth and adults should have achieved at least a minimum level of proficiency in sustainable digital skills; 40 percent of the world's population should be using digital financial services; unconnectedness of micro-, small- and medium-sized enterprises should be reduced by 50 percent, by sector; and gender equality should be achieved across all targets.

The Broadband Commission for Sustainable Development engages in high-level advocacy to promote broadband in developing countries and underserved communities. One of the central roles of the Commission is to promote the importance of broadband on the international policy agenda. In doing so, Commissioners work together to devise practical strategies—including private-public partnerships—that advocate for higher priority to be given to the development of broadband infrastructure and services, to ensure that the benefits of these technologies are realized in all countries and accessible to all people.

EU Reports on Financing Breakthrough Innovation

In its report, entitled "Europe Is Back: Accelerating Breakthrough Innovation," the independent High-Level Group of Innovators advising the European Commission recommends that a future European Innovation Council (EIC) provides simplified and flexible financing, tailor-made for the needs of the innovator and which incentivises private investment for rapid scaling up. It also recommends boosting awareness of Europe's innovation successes and leveraging European ecosystems, so that highly innovative companies can benefit from expertise and partnerships across Europe.

> "...Europe's innovation successes..."

Commissioner for Research, Science and Innovation Carlos Moedas welcomed the recommendations and said they formed a significant input for the development of a fully-fledged EIC as part of the next EU Framework Programme for Research and Innovation.

Commissioner Moedas said: "These recommendations show how a EIC would empower our most talented innovators and stimulate an environment of risk-taking, entrepreneurship and scaling-up to the international stage. They come at a critical time in the preparations for the next EU research and innovation programme."

New Wearables for Assessment of Frailty

The FRAILSAFE project, supported by the European Union, is doing what it can to further understanding of frailty and to develop measures to define it. One development the project has made is the Wearable Wireless Body Area Network System (WWBS) that can measure several crucial parameters, enabling doctors and nurses to get a clear idea of their patients' health in an unobtrusive manner.

The WWBS comprises a sensor-packed garment—a T-shirt—that contains two fabric electrodes for electrocardiogram (ECG) monitoring and a fabric piezorestistive sensor for respiration monitoring on the chest. Each of the sleeves contain a small box which houses a 9-Degrees of Freedom (DoF) inertial measurement unit (IMU) sensor. On the chest there is also a pocket for an electronic device with a third, integrated 9-DoF IMU.

This device collects all the information gathered by the shirt and stores it on a micro SD card. When need-

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"...understanding of frailty..."

ed, data can be transmitted via Bluetooth™ to a computer or an Android device for real-time analysis.

The project has entered its next phase with the development of the second iteration of the FRAILSAFE Smart Vest, which is produced by project partner Smartex. Designers first issued a prototype at the end of 2016 to partners for testing. From May 2017, project volunteers participating in Nancy, Nicosia and Patras tried out the vest and gave feedback on the 1.0 version. As a result 15 version 2.0 garments were produced and delivered to the FRAILSAFE pilot sites at the end of 2017 for the next stage of evaluation.

Saab and Lund University Reach Research Agreement

Saab and Lund University in Sweden have signed a collaboration agreement concerning research, innovation and education. The agreement is a platform for long term and strategic competence provisioning, providing added value to mutually strengthen Lund University and the Saab Group.

"...technological and societal challenges..."

"Saab has a long and successful history of university collaborations, including Lund University. The agreement will strengthen the collaboration and give us access to competencies at Lund University in strategic areas to Saab," said Håkan Buskhe, president and CEO of Saab.

Together, Lund University and Saab will develop activities within education and research for the benefit of both parties, and make competence, resources and facilities available to both parties. Among the focus areas for the collaboration are electromagnetic field theory, computer sciences, energy sciences and structural mechanics.

"Saab is an important strategic partner. We have collaborated with them for a long time on a number of projects. By deepening and formalising the collaboration, we see even greater opportunities to develop research, education and innovations together. Academia and the business sector need to work closely and in the long term to solve today's complex technological and societal challenges," said Torbjörn von Schantz, vice-chancellor of Lund University.

Global Smart Cities IoT Technology Revenues to Exceed US$60B by 2026

IoT technology revenues across 12 key smart city technologies and verticals will grow from around US$25 billion in 2017 to US$62 billion in 2026 at an average growth rate of 11 percent. According to ABI Research, while smart meters and video surveillance represent the largest absolute revenue opportunities, the fastest growing verticals include EV charging stations and micro-grids, smart waste management and environmental sensors, smart parking and smart street lighting.

"Interest in and focus on smart cities has skyrocketed in 2017, with a very large number of vendors from across the value chain repositioning and optimizing their IoT portfolios to take advantage of this beckoning opportunity," says Dominique Bonte, vice president at ABI Research. "By its very nature of aggregating a wide range of solutions and technologies, the smart cities segment offers the perfect environment for suppliers to offer horizontal IoT platform solutions and addresses a recent trend toward more holistic, cross vertical approaches."

> Smart Meters and Video Surveillance represent the highest revenue opportunities exceeding US$20B by 2026.

When considering IoT revenue categories, the largest rewards can be reaped from the higher levels of the value chain, including applications and services, analytics and AI and security. Connectivity, sensor and device management, as well as professional services, represent decreasing opportunities against a background of increasing platformization and commoditization.

Key smart city IoT solutions and platforms include Cisco's Kinetic for Cities, InterDigital's Chordant, PTC's ThingWorx, Microsoft's CityNext, Huawei's OceanConnect, Nokia's Impact, NVIDIA's Metropolis, Verizon's NetSense (Sensity), Siemens' MindSphere, IBM's Watson IoT, SAP's Leonardo and Amazon's AWS IoT platform.

While many, if not all, IoT technology suppliers are now directing their gaze firmly toward smart cities, only the ones addressing the specific challenges cities are facing will win. Critical success factors include flexible, extensible "as a service" or "pay as you grow" offers, financing and ecosystem support, standards-based interoperability and guaranteed technology lifecycle management. Simply applying a thin layer of marketing veneer on top of an otherwise generic IoT platform will not allow vendors to cut to the chase.

US$18B Market for AR in Energy and Utilities as it Augments Worker Safety

Energy and utilities rank among the top three verticals in terms of augmented reality (AR) glasses shipments and total value chain revenues. AR's ability to enhance workers' safety and protect equipment addresses the priority on safety emphasized by the energy and utilities industry. ABI Research estimates the energy and utilities sector will account for 17 percent of global smart glasses shipments in 2018. Total AR market revenues for the energy and utilities industry are expected to grow to US$18 billion by 2022, with platform and licensing, and smart glasses hardware comprising the majority.

"AR enables better visualization of underground assets, pipelines in concrete, or complex components, which helps to avoid breaks while digging, detect dangerous leaks and reduce accidents. Accordingly, employee safety is maintained along with a decline in errors and total downtime," says Marina Lu, senior analyst at ABI Research. "As the industry faces a lack of skilled workers and an aging workforce that will result in knowledge loss, AR will aid field workers by connecting them with remote experts who can provide real-time guidance and highlight where extra caution should be taken. A subsequent benefit is that the information obtained from AR solutions can be stored as a guideline for future work, thus facilitating business decisions and workflow. With AR, employees become more proficient more quickly."

> "Ensuring safety while improving efficiency—a unique and attractive combination for the industry."

The Electric Power Research Institute (EPRI) has studied the importance of AR to the energy industry and has been involved in several vendor efforts to investigate and pilot the use of AR in electric and utility operations. EPRI has also collaborated with Duke Energy, deploying Atheer's AR platform to demonstrate the AR application benefits of improved productivity and safety due to hands-free data access. GE Renewable Energy has improved technician assembly time efficiency by 34 percent using smart glasses overlaid with digital instructions. Upskill's Skylight platform enables the technicians to use voice to identify certain items such as wires and find locations, which saves time over reading paper manuals. Also, Siemens partnered with DAQRI and conducted a study to explore how AR-based gas burner assembly can increase training efficiency and reduce errors.

"Safety is a dominant theme for energy and utilities. Durable and dependable AR devices can operate well

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in potentially hazardous environments such as those with explosive dust or flammable gas," adds Eric Abbruzzese, principal analyst. "These environments also have the strongest need for worker safety improvements that can be provided by AR devices. Real-time environment monitoring, safety notifications and workflow instruction can ensure safety while improving efficiency—a unique and attractive combination for the industry."

IoT Identity and Management A US$21.5B Opportunity

According to ABI Research, IoT Platform services along with security, cryptography, digital certificate management and data exchange services are propelling IoT Identity and Management revenues toward US$21.5 billion by 2022.

"Through 'smarter gateways,' cloud services and application programming interface (API)-focused solutions, thing identity and management services are steadily finding their way in a wider spectrum of IoT verticals," comments Dimitrios Pavlakis, industry analyst at ABI Research. Although certain verticals are still lagging in terms of security, IoT vendors are finally starting to invest more on encryption and device certificate management. Aftermarket telematics, fleet management, OEM telematics, metering, home security and automation are among the most important verticals absorbing more than 60 percent of the total revenues worldwide.

"This brings us one step closer to the realization of IAM (identity and access management) 2.0," continues Pavlakis. "We are entering a transformational period where device IDs, system IDs and user IDs are forced to merge under the hyper-connected IoT paradigms, effectively altering the way the indentity of things (IDoT) will be perceived from now on." To that end, open IoT standards and frameworks like OCF, OneM2m and DeviceHive are attempting to create OS/RTOS/Vendor-agnostic solutions to reduce friction for more interconnected and secure ecosystems.

While some vendors choose to offer wide-ranging IoT solutions, most of them are seeing the merit of specialization in IDoT: enterprise and industrial (Microsoft Azure), connected agriculture (Bosch), advanced analytics and machine learning (SAP), cryptography and device management (Rambus), as well as energy and manufacturing (GE Predix). Given recent public key infrastructure success stories in securing IoT devices, this specialization trend extends to most of the certification authorities too: smart city, transportation and healthcare (DigiCert), cloud service providers (GlobalSign), banking and finance (IdenTrust) and enterprise and consumer (Comodo).

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Waveguide Band (GHz)	**WR28** 26-40	**WR15** 50-75	**WR12** 60-90	**WR10** 75-110	**WR8** 90-140	**WR6.5** 110-170	**WR5.1** 140-220	**WR4.3** 170-260	**WR3.4** 220-330	**WR2.8** 260-400	**WR2.2** 325-500	**WR1.5** 500-750	**WR1.0** 750-1,100
Dynamic Range (BW=10Hz, dB, typ)	120	120	120	120	120	120	120	115	115	100	110	100	65
(BW=10Hz, dB, min)	110	110	110	110	110	110	110	100	105	80	100	80	45
Magnitude Stability (±dB)	0.15	0.15	0.15	0.15	0.15	0.25	0.25	0.3	0.3	0.5	0.5	0.8	0.5
Phase Stability (±deg)	2	2	2	2	2	4	4	6	6	8	8	10	6
Test Port Power (dBm)	10	13/6	13/6	11/6	6	9	-1	-2	-6	-10	-8	-25	-30

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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

VIAVI Solutions has announced its intention to acquire the test and measurement business of **Cobham plc** for $455 million cash. The acquisition has been approved by the board of directors of both the company and is expected to close during the second half of VIAVI's fiscal year 2018, subject to obtaining clearance under the Hart-Scott-Rodino Antitrust Improvements Act, as well as other customary closing conditions. The transaction will significantly strengthen VIAVI's competitive position in 5G deployments and diversify the company's portfolio to support the military, public safety and avionics test markets.

Littelfuse Inc. announced the completion of its acquisition of **IXYS Corp**. IXYS is a global pioneer in the power semiconductor market with a focus on medium- to high-voltage power semiconductors across the industrial, communications, consumer and medical device markets. The transaction is expected to be immediately accretive to adjusted EPS. Littelfuse expects to achieve more than $30 million of annualized cost savings within the first two years after closing. The combination is also expected to create significant revenue synergy opportunities longer term, given the companies' complementary offerings and combined customer base.

COLLABORATIONS

Keysight Technologies Inc. announced it has reached a new milestone in low-frequency noise measurements through its work with leading research centers in Europe, Middle East, Africa and India (EMEAI). Using the new Advanced Low-Frequency Noise Analyzer (A-LFNA) and WaferPro Express software, designers can now measure noise more accurately in an even broader range of electronic devices. Noise is one of the main limiting factors in electronic devices, including sensitive parts such as sensors and memories. As a result, the ability to monitor noise using a statistical approach on a large number of samples and different devices is more critical than ever before.

Skyworks Solutions Inc. announced that its new portfolio of 802.11ax wireless connectivity solutions are being leveraged by **Broadcom** in their recently launched Max WiFi reference platforms. Skyworks' innovative modules integrate high-power transmit and low-noise receive amplification with precision switch capability in an ultra-compact form factor that when paired with a modem, incorporate all the essential functionality between the system-on-a-chip (SoC) and the antenna. Specifically, Skyworks' 2.4 and 5 GHz 802.11ax modules and Broadcom's Max WiFi solutions provide 4× faster download speeds, 6× faster upload speeds, enhanced coverage and up to 7× longer battery life when compared to 802.11ac Wi-Fi products available in the market today.

NEW STARTS

Microwave Journal has published an enhanced online Design Tools section with a compilation of tools, software, calculators, spreadsheets and more that RF and microwave engineers can utilize or download. A description, graphic and link are available for each tool for quick reference. The library includes offerings from leading RF/microwave companies such as Analog Devices, Pasternack, NI/AWR, Keysight, CST, ANSYS, Sonnet, Comsol, MathWorks, Remcom, Custom MMIC, Mician, Rogers, K&L, Coilcraft and more. The new Microwave Journal Design Tools section is available at www.microwavejournal.com/designtools. The editors will continue to improve and extend the Design Tools section, so bookmark the URL for continued reference.

Signal Integrity Journal, the sister publication to *Microwave Journal* covering signal integrity, power integrity and EMC/EMI related topics, has published its first printed magazine issue. *Signal Integrity Journal* was launched in September 2016 as an online magazine, and is now celebrating its success with this 2018 print edition, which is also available as a digital e-book. The issue has long form technical articles on signal integrity, power integrity and EMC/EMI subjects plus shorter form columns covering these topics with practical, expert advice about designing high speed circuits for optimal performance at the lowest cost. The magazine issue is available in print, distributed at worldwide SI/PI/EMI events, and as a PDF download online at www.signalintegrityjournal.com/2018magazine.

Peregrine will operate under a new name, **pSemi Corp**. pSemi will have the same experienced leadership team, but will have a broader scope and an expanded product portfolio. When Murata acquired Peregrine in December 2014, they kept the Peregrine brand name untouched. In the last few years, Murata has asked the team to extend their reach, increase their intellectual property (IP) portfolio and grow on a global scale to support more semiconductor innovations. It is time to signify this shift and update how the company represents itself to the market. The name change also coincides with two major milestones: the 30-year anniversary of RF-CMOS innovation and the shipment of their four billionth chip.

Murray Pasternack, founder, CEO and sole owner of Pasternack Enterprises in Irvine, Calif. from 1972 to 1992, announced the launch of **RF Superstore** (www.rfsuperstore.com), an online supplier of RF and microwave components. Joining Pasternack is Jason Wright, managing partner of The Riverbend Co., an investment group with several service, manufacturing and distribution-related investment holdings. As CEO, Wright will manage the day-to-day operations of the business while working closely with Pasternack to develop RF

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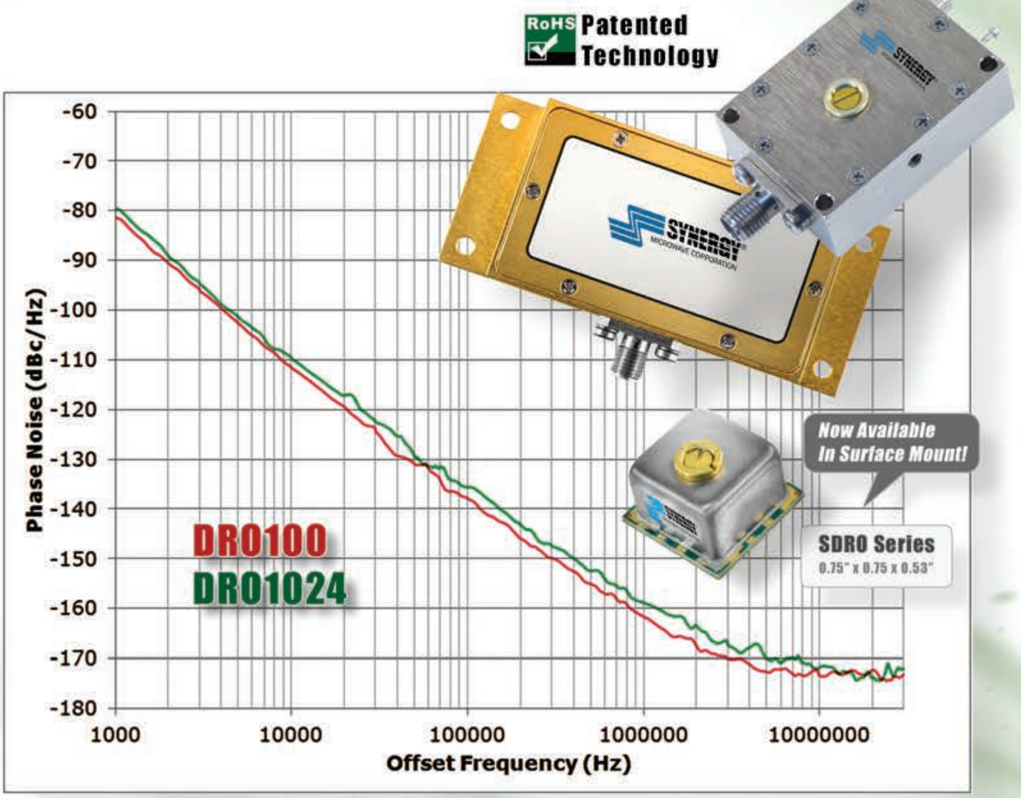

Model	Frequency (GHz)	Tuning Voltage (VDC)	DC Bias (VDC)	Typical Phase Noise @ 10 kHz (dBc/Hz)
Surface Mount Models				
SDRO1000-8	10	1 - 15	+8 @ 25 mA	-107
SDRO1024-8	10.24	1 - 15	+8 @ 25 mA	-111
SDRO1250-8	12.50	1 - 15	+8 @ 25 mA	-105
Connectorized Models				
DRO100	10	1 - 15	+7 - 10 @ 70 mA	-111
DRO1024	10.24	1 - 15	+7 - 10 @ 70 mA	-109

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Superstore into a world-class supplier of RF and microwave components.

Anokiwave Inc., an innovative company providing highly integrated IC solutions for mmWave markets and active antenna based solutions, announced the opening of a mmWave design verification laboratory in its San Diego office. The new laboratory enables rapid characterization of Anokiwave's world-class product portfolio mmWave ICs for 5G, SATCOM and radar markets. The laboratory includes state of the art test instrumentation and wafer probing capability up to 50 GHz that supports both rapid characterization of new products and increased applications engineering evaluation capacity.

ACHIEVEMENTS

Akash Systems, a company focused on resolving the explosive growth of data consumption by enabling smarter and lighter satellite systems, has raised $3.1 million to close its seed funding round. Led by Khosla Ventures, the seed round also included Social Capital, Data Collective, Ruvento Ventures, Sriram Krishnan and Backstage Capital. The funding will allow Akash to further its mission of reimagining tomorrow's communication systems by developing the next generation of small satellites and the components that power them.

Harris C4i Pty. Ltd., an Australia-based operation of Harris Corp., has been recognized among the most successful and innovative export operations in the State of Victoria. The business received the prestigious Victorian Export Award for Innovation Excellence during the 2017 Governor of Victoria Export Awards (GOVEA) held in Melbourne and hosted by the Honourable Linda Dessau AC, governor of Victoria. Harris C4i is a global leader in IP and data distribution service-based secure voice communications for mission-critical environments. The organization's interoperable communications solutions are used in more than 35 countries by a wide range of industries—including aviation, defence, public safety, utilities and transport.

For any technology to scale within an open ecosystem with multiple vendors it is critical to give confidence of interoperability. Therefore, one of the goals of the **LoRa Alliance** for 2018 is to increase the number of certified devices available in the market. Consequently, the LoRa Alliance has started a dedicated incentive promotion program for LoRaWAN™ device, sensor and module manufacturers. Now, LoRaWAN Certification and RF performance evaluation will be sponsored for a certain time by the LoRa Alliance. Being certified gives manufacturers the right to use the official LoRaWAN Certified logo and it helps to market their products accordingly.

A Danish defense agreement for the years 2018-2023 has been reached supported by the government, The Danish People's Party, The Social Democrats and The Social-Liberal Party. As a key industrial leader and technology leader, the agreement is a key driver for future defense activity for Denmark's **Terma A/S**, prompting the company's CEO and President Jens Maaløe to state: "We are pleased to see the outcome of the political negotiations for the Danish defense sector and the support for the agreement across the political parties in the Danish Parliament. The agreement brings Denmark closer to meeting NATO's defense investment and spending goals."

CONTRACTS

Kaman Corp. announced that its aerospace segment has been awarded a direct commercial sale (DCS) order for the procurement of joint programmable fuzes (JPF) with an expected total value of $324 million. Delivery of the fuzes is anticipated to begin in 2019 and continue through 2022. Kaman has been the sole provider of the JPF to the USAF since 2002. In addition to the USAF, Kaman provides the JPF to 26 other nations. The JPF allows the settings of a weapon to be programmed on wing in flight and is the current bomb fuze of choice of the USAF.

The **U.S. Navy** has awarded **BAE Systems** a $46.8 million contract option to deliver four additional Mk 45 Naval Guns. The contract modification calls for upgrading existing guns to the Mod 4 configuration to increase the firepower and extend the range of the weapons. This modification to the initial 10-gun contract brings the full value of the award to $176.8 million for the 14 guns.

Mercury Systems Inc. announced it received $3.4 million in follow-on orders from a leading defense prime contractor for custom high performance microelectronics integrated into the guidance, navigation and control system of a precision guided munitions application. The orders were booked in the company's fiscal 2018 second quarter and are expected to be shipped over the next several quarters.

The **U.S. Air Force** has selected **Harris Corp.** to provide engineering support services for the electronic warfare (EW) systems onboard the international variant of the F-16. The contract was awarded during the second quarter of Harris' fiscal 2018. Harris will provide software updates and engineering support for its AN/ALQ-211(V)4/8/9 Advanced Integrated Defensive Electronic Warfare Suite (AIDEWS) systems that protect the fleets of F-16s from eight other countries against evolving electronic threats.

Orbital ATK was awarded a developmental contract by the **U.S. Navy** for the Advanced Anti-Radiation Guided Missile-Extended Range (AARGM-ER) upgrade. The contract will mature the AARGM-ER configuration resulting in a preliminary design prior to entry into the Engineering and Manufacturing Development phase. The AGM-88E AARGM, currently in Full Rate Production, is a supersonic, air-launched tactical missile system that upgrades legacy AGM-88 High Speed Anti-Radiation Missile systems with advanced capability to perform Destruction of Enemy Air Defense missions.


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Around the **Circuit**

L3 Technologies announced that it has delivered the first production HC-130J aircraft integrated with a next-generation Minotaur Mission System Suite (MSS+) to the **U.S. Coast Guard** for improved long-range surveillance capabilities. Work was done by L3's Aerospace Systems business segment and an aircraft completion ceremony was hosted at its facility in Waco, Texas. L3 upgraded the aircraft with the government-furnished MSS+ that was developed jointly by the U.S. Coast Guard and the U.S. Navy, and operated across multiple platforms. Work included integration and testing of the aircraft under the competitively awarded five-year contract.

As an extension of a current service contract, **General Electric (GE)** was chosen by the **U.S. Navy's Military Sealift Command (MSC)** for GE's Predix Asset Performance Management (APM) pilot program onboard two T-AKE replenishment dry cargo ammunition vessels—William McLean (T-AKE 12) and Medgar Evers (T-AKE13)—to improve performance and mission readiness. The MSC is the leading provider of ocean transportation for the U.S. Navy and the DoD—operating approximately 120 ships daily around the globe.

Sypris Electronics LLC, a subsidiary of Sypris Solutions Inc., announced that it has recently received contract awards to manufacture a variety of mission-critical electronic assemblies for a number of global undersea communication projects. The name of the customer and the terms of the agreements were not disclosed. The awards are for the production of a variety of electronic assemblies used in undersea cable transmitters. These transmitters deploy advanced reconfigurable optical add-drop multiplexing technology, which is essential for the optimization and efficiency of today's high-capacity, transoceanic cable systems. Production will begin in 2018.

PEOPLE


▲ *Greg Evans*


▲ *Ross Berntson*

Indium Corp. has promoted **Greg Evans** to CEO, and **Ross Berntson** to president and COO. Former CEO and company owner William Macartney III will continue serving as the chairman of the board. Evans has been with Indium Corp. for 36 years. He began as a technical support engineer and quickly rose to product line manager, helping expand the company's product lines into the SMT assembly field. Berntson joined Indium Corp. in 1996 as a product specialist. He quickly rose to the roles of product manager, marketing leader, sales leader, tech support leader and, most recently, as executive vice president.

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S - SERIES (X - Standard, O - Optional)	MODEL SA1241	MODEL SPA1241
Spectrum Analyzer (100 KHZ - 12.4 GHz)	X	X
Dual Signal Generator (54 MHZ - 13.6 GHz)	X	X
Four Channel Scope (4 CH - 200 MHz)	X	X
Tracking Generator (100 KHZ - 12.4 GHz)	O	O
RF Power Meter (CW/Pulse/PK - 10 MHz - 10 GHz)		X
Power Amplifier 1 (1 Watt / 100 MHz - 18 GHz)		X
Power Amplifier 2 (25 Watts / 700 MHz - 6000 MHz)		O
RF Relay - SPDT (35 Watts / DC - 18 GHz)		X
RF Attenuator (10 Watts / DC - 18 GHz)		X

Other Models: 4.4 GHz system (Model SA441 and Model SPA441)
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Around the **Circuit**

▲ *Manfred Mettendorff*

DEV Systemtechnik has appointed **Manfred Mettendorff** as managing director. With more than 22 years of experience in the global communications and IT industry at Fujitsu Semiconductors and Socionext, he brings unique qualifications to the role. Mettendorff holds an engineering degree in electronics with a major in communications. Based in Germany and temporarily in Silicon Valley, Calif., he has held various managing positions in marketing, sales, business development and engineering, and has directed entire business units.

REP APPOINTMENTS

RFMW Ltd. and **Keysight Technologies** of Santa Rosa, Calif., have announced a distribution agreement effective January 2, 2018. Keysight designs and manufactures high frequency, InP and GaAs MMIC devices providing broadband performance from DC to 110 GHz. Product families include switches, attenuators, amplifiers, mixers, limiters, frequency doublers, detector diodes and prescalers. RFMW Ltd. is a specialized distributor providing customers and suppliers with focused distribution of RF and microwave components as well as specialized component-engineering support. Under the agreement, RFMW is franchised worldwide for Keysight's MMIC portfolio.

PLACES

Defense and security company **Saab** is expanding its activities in Finland through the establishment of the new Saab Technology Center (STC) in Tampere, Finland. The first stage has been to establish a unit at the STC with a focus on EW. The unit contributes to deliveries for the company's current EW contracts for fighter aircraft, including Gripen E/F, the EW system for Airborne Early Warning & Control (AEW&C) aircraft and the Electronic Support Measures/Electronic Intelligence systems (ESM/ELINT) used for land applications.

Filtronic has opened its new North American service and repair center, at its existing premises in Salisbury, Md. The updated facility now enables the company to carry out repair and refurbishment of antenna and filter products in the U.S., reducing logistics lead times and costs for our customers. This new capability adds to the company's existing offerings of sales and engineering support, local U.S. warehousing, rapid order fulfillment and local product configuration for customers.

The Unmanned Systems Division of **Kratos Defense & Security** Solutions is opening a new facility in Oklahoma City. This new facility will cater to the increase in demand for high performance, jet powered unmanned aerial tactical and target drone systems. Advanced military target drones with fighter-like performance has been Kratos's forte.

INVITED PAPER

Combining MMIC Reflectionless Filters to Create UWB Bandpass Filters

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Reflectionless filters provide a novel approach to filter design and offer several practical advantages over conventional microstrip designs for ultra-wideband (UWB) applications. In addition to delivering superior electrical performance, they are smaller, lower cost and more repeatable making them suitable candidates for use in commercial applications where volume manufacturability may be a requirement. Design examples are provided.

Ultra-wideband (UWB) is defined as any RF radio technology utilizing a bandwidth of greater than 25 percent of the center frequency or a bandwidth greater than 500 MHz.[1-2] While UWB has been around since the end of the 19th century, restrictions on transmission to prevent interference with narrowband continuous wave signals have limited its applications to defense and relatively few specially licensed operators.[1] In 2002, the FCC opened the 3.1 to 10.6 GHz band for commercial applications of UWB technology; since then, it has been a focus of academic study and industry research for a promising variety of emerging applications. To prevent interference with neighboring spectrum allocations, such as GPS at 1.6 GHz, the FCC has imposed specific rules for indoor and outdoor transmission, limiting transmissions in the permitted frequency range to power levels of -41 dBm/MHz or less.

Research has explored many potentially valuable applications. For example, the wide bandwidth provides high channel capacity, allowing high speed data transfer at very low power. While the FCC power mask limits the range of UWB transmission to within roughly 10 m, its high speed, low-power characteristics make it an attractive technology for certain short-range machine-to-machine (M2M) communication applications like wireless personal area networking and low power sensor networks.[1]

UWB has proven viable for new applications in detection, positioning and imaging. Modulation of UWB signals using ultra-short pulses, on the order of nanoseconds, enables precise location and ranging to the cm level.[1,3] This has potential for use in military surveillance systems and other high-accuracy location and detection applications. Its high resolution, high penetration properties have also attracted research in the medical field. For example, UWB systems have been used for noninvasive, precise detection of heart movements and for high fidelity imaging using safe, nonionizing radiation, as an alternative to more harmful X-ray imaging.[4]

UWB technology has shown much potential, but design challenges remain in bringing it to a stage of wider industry adoption and commercialization. One of those challenges is the development of RF filters with wide enough passbands, flat response and sufficient selectivity to meet FCC spectral masking specifications. Several approaches have been studied utilizing microstrip technology.[2,5-6] While achieving varying degrees of success, each have drawbacks. In general, microstrip UWB filters are large, typically occupying greater than 1 in.^{2} of board space, and tend to be too costly for volume production.

REFLECTIONLESS FILTERS FOR UWB RF FRONT ENDS

Reflectionless filters provide an attractive alternative to existing approaches. Because

reflectionless filters absorb and terminate stopband signals, rather than reflecting them back to the source, they can be cascaded in multiple sections without generating standing waves and causing distortion of the passband shape. This facilitates the combination of low and highpass filters to create a bandpass response, a technique that is useful in designing UWB filters. Reflectionless highpass filters have broad enough passbands to achieve the desired bandwidths for UWB, while most other filter technologies do not; reflectionless lowpass filters offer cut-offs that extend high enough in frequency to achieve 3 dB bandwidths well above 100 percent.

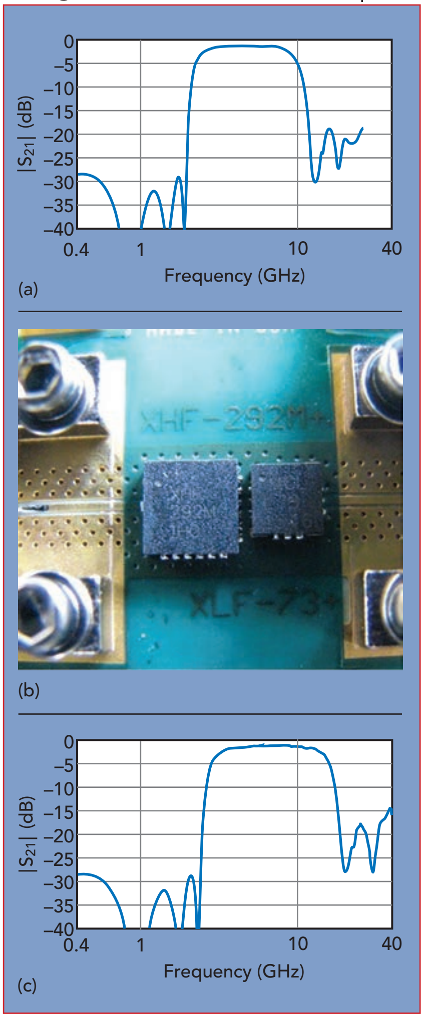
While competing approaches employ transmission lines, reflectionless filter topologies are based on lumped elements using MMIC technology. Smaller size, lower cost and greater repeatability make them more suitable candidates for volume production. Filter models are available in package sizes as small as 2 mm × 2 mm and as bare die for chip-and-wire integration.

CASE STUDIES

The remainder of this article describes the use of reflectionless filters in UWB filter design, with examples using filters available from Mini-Circuits to demonstrate their advantages. Simulated performance is compared with measured results, and a final design is shown that meets UWB bandwidth requirements and the specifications of the FCC spectral mask.

Case 1: General Proof of Concept

Two reflectionless filters, Mini-Circuits highpass (2.9 to 8.7 GHz) and lowpass (DC to 7 GHz) models, are combined to create a bandpass response. The simulation shown in ***Figure 1a*** exhibits a 3 dB pass-



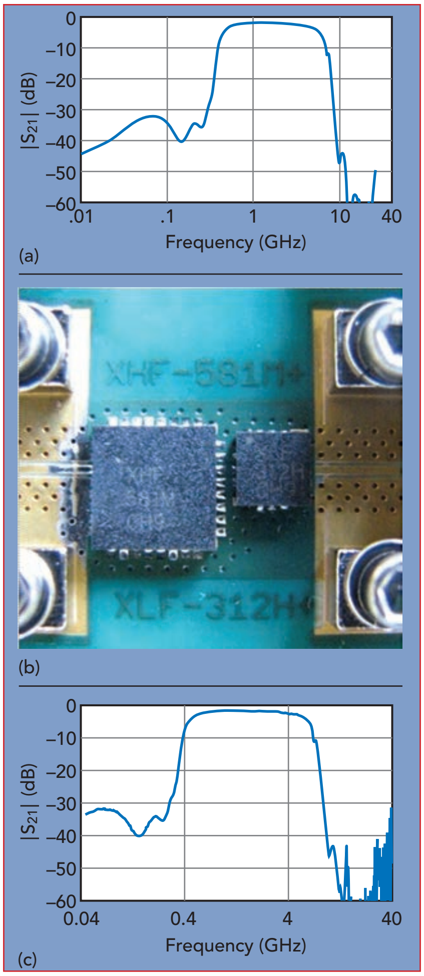
▲ Fig. 1 Simulated response combining XHF-292M+ with XLF-73+ (a), devices in the test fixture (b) and measured results (c).

band from 2.3 to 9.7 GHz (4.2:1 or 123 percent bandwidth). To validate these results, the filters are mounted in the test fixture shown in ***Figure 1b***. Insertion loss is swept from 0.1 to 40 GHz and again from 45 MHz to 2 GHz, the latter with fine resolution to capture the low frequency details. After correcting for fixture loss by subtracting the measured loss of a straight thru-line, the measured data for the combined filter is plotted in ***Figure 1c***. The response exhibits a 3 dB passband from about 2.4 to 9.7 GHz (4:1 or 121 percent bandwidth). Cascading has no effect on the passband flatness. The higher rejection on the low frequency end is due to the two-section design of the highpass filter.

Case 2: Maximizing Bandwidth

Case 1 establishes the viability of combining highpass and lowpass reflectionless filters to create UWB bandpass response. The same technique can be used with different filter models to shape the response. In this case, two-section highpass and three-section lowpass models (0.58 to 3 GHz and DC to 3.53 GHz, respectively) are combined to create the widest possible passband. In addition to a wide bandwidth, because this combined filter incorporates two- and three-section designs, it also exhibits high rejection in both the upper and lower frequency stopbands.

A simulation combining these two models in series is shown in ***Figure 2a***, exhibiting a 3 dB passband from 450 MHz to 5.7 GHz (12.7:1 or 171 percent bandwidth). A logarithmic frequency scale is used to better show the shape of the response. Note the lower frequency stopband rejection greater than 30 dB and upper frequency stopband rejection of 50 to 60 dB.



▲ Fig. 2 Simulated response combining XHF-581M+ and XLF-312H+ (a), devices in the test fixture (b) and measured results (c).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The filters are shown mounted in their test fixture in ***Figure 2b***. Insertion loss is measured as in Case 1 and shown in ***Figure 2c***. The filter achieves a 3 dB bandwidth from about 500 MHz to 5.2 GHz (10:1 or 165 percent bandwidth). The measured data exhibits a slightly narrower passband than the simulation, yet still achieves greater than a full decade of bandwidth. The lower stopband rejection is between 30 and 40 dB, and the upper stopband rejection ranges from 40 to greater than 60 dB, corresponding to the simulation. The passband shows excellent flatness with no distortion from adverse interactions between the filter stages.

Case 3: Confirming Stopband Rejection to 40 GHz Without Re-Entry

Cases 1 and 2 illustrate that cascaded reflectionless filters can achieve ultra-wide passbands, enabling bandwidths at least to a full decade, to support the bandwidth requirements of UWB applications. Another concern for system designers is the potential for "re-entry" out of the band at higher frequencies. Such unintentional radiation can potentially interfere with signals at neighboring frequencies and violate FCC rules. Therefore, UWB filters must exhibit good stopband rejection without re-entry to a very high frequency. In part due to their fabrication using MMIC technology, reflectionless lowpass filters provide stopband rejection extending to 40 GHz. Many conventional filter approaches would suffer re-entry over this bandwidth.

In this case, a highpass model (2.01 to 10.1 GHz) and lowpass model (DC to 7 GHz), both single-section designs, are combined. Simulation results for the combined filter are shown in ***Figure 3a***, demonstrating a 3 dB passband from

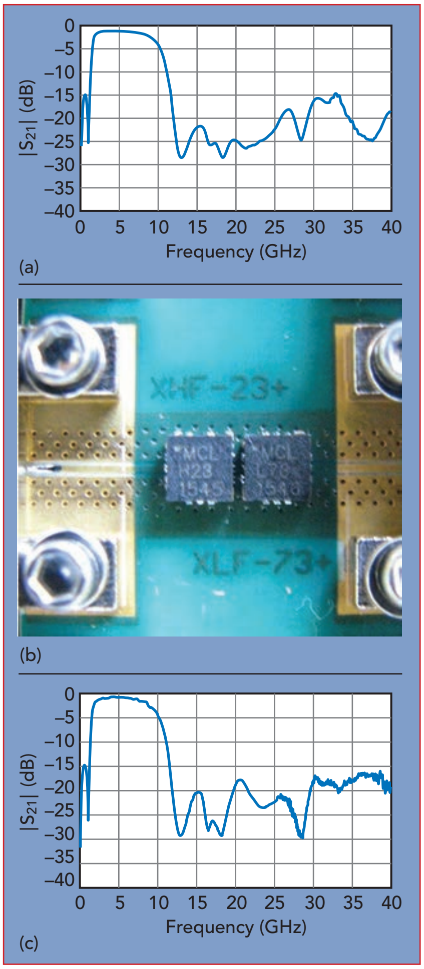
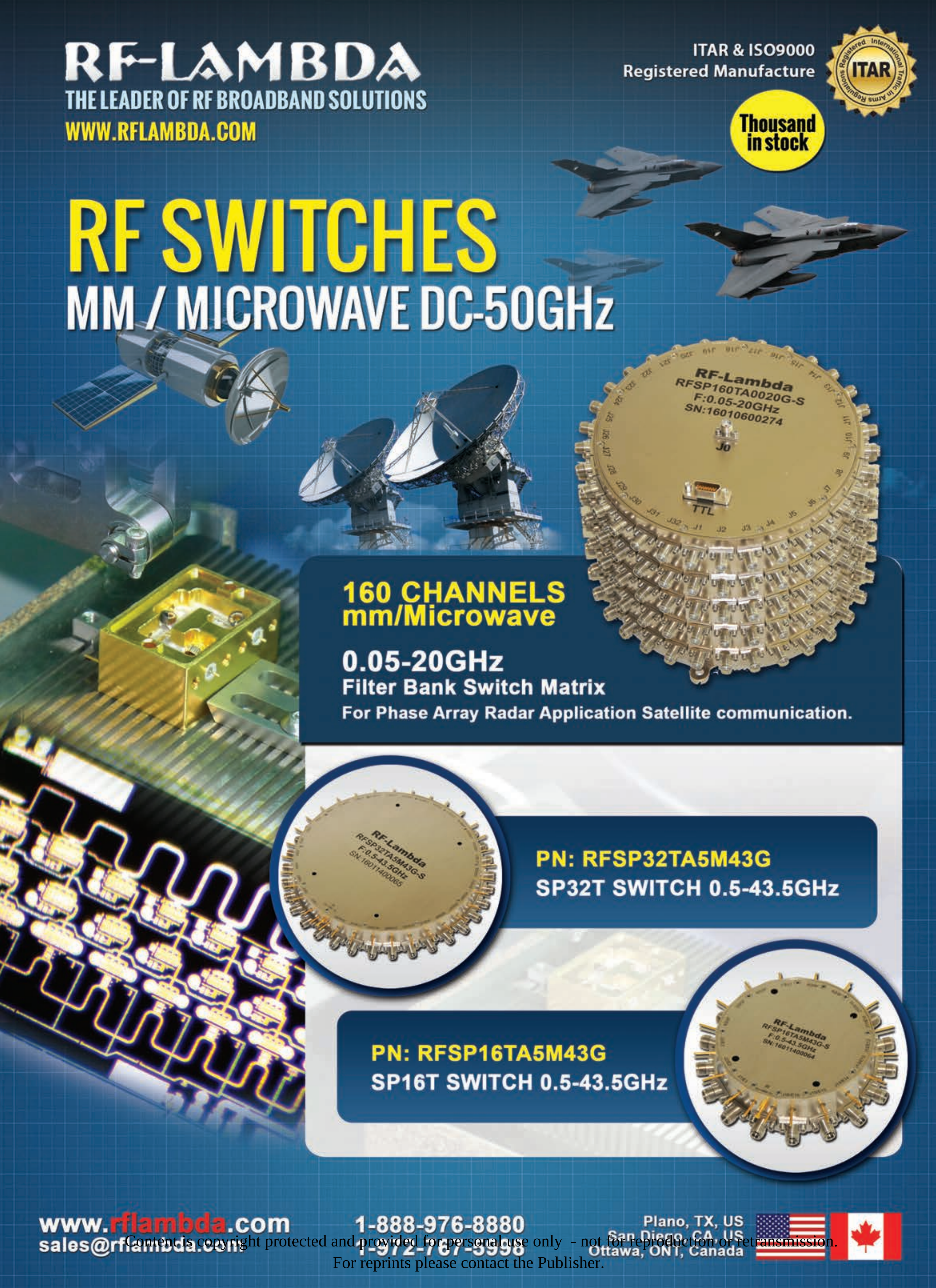


Fig. 3 Simulated response combining XHF-23+ and XLF-73+ (a), devices in the test fixture (b) and measured results (c).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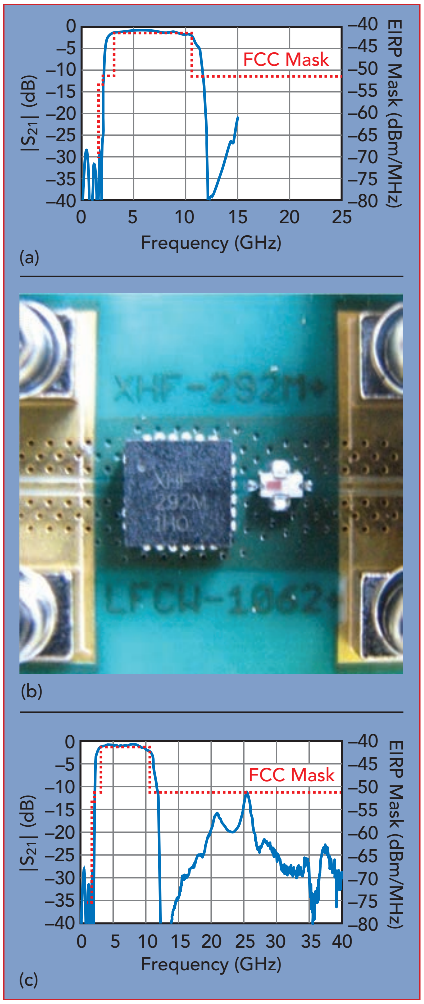
1.6 to 10 GHz (6.25:1 or 145 percent bandwidth). Stopband rejection remains better than 15 dB up to 40 GHz without re-entry. ***Figure 3c*** plots the measured insertion loss of the test board shown in ***Figure 3b***. The measured response shows a 3 dB passband from about 1.7 to 9.3 GHz (5.5:1 or 138 percent bandwidth), with stopband rejection well above 15 dB up to 40 GHz, confirming that this technique can be used in UWB applications without unintentional out-of-band emissions due to re-entry.

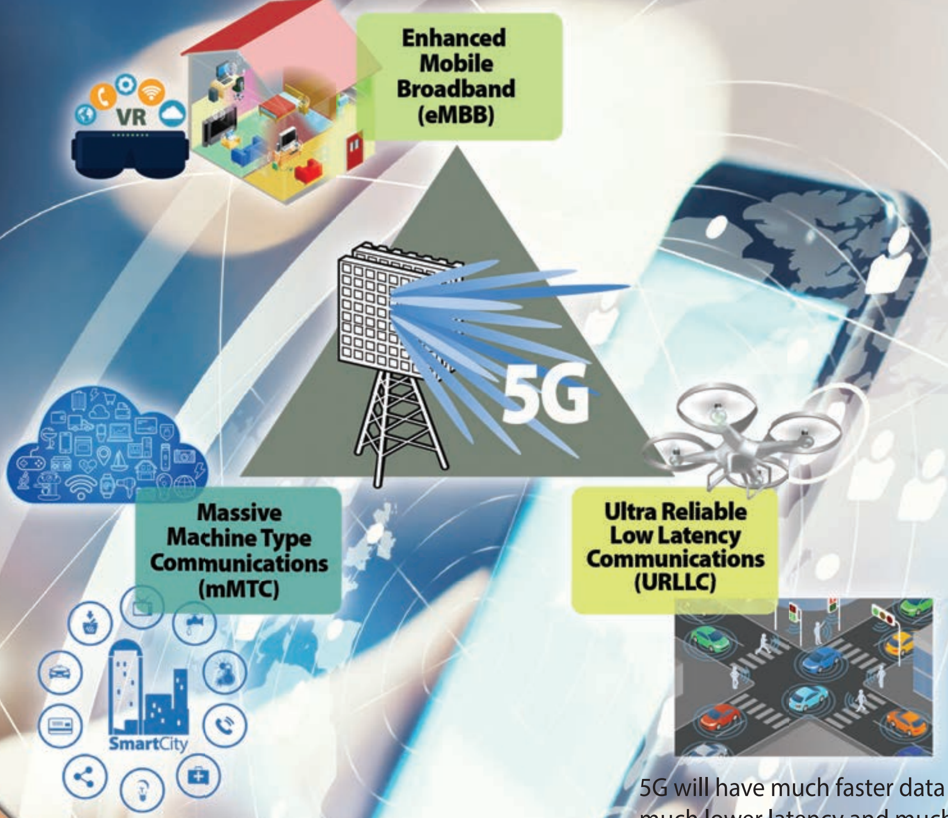
Case 4: Adding LTCC Filters to Sharpen Selectivity

We have shown that reflectionless filters can be combined to achieve ultra-wide passbands and that this approach provides excellent stopband rejection up to 40 GHz without re-entry. To come closer to real world requirements of UWB systems under FCC specifications, it may be necessary to sharpen the transition to conform to the FCC spectral mask.

The absorptive characteristic of reflectionless filters means that they are not only cascadable with other reflectionless filters, but with all manner of conventional filters. This hybrid approach enables the desired wideband response while incorporating the selectivity of another filter technology. In this case, a two-section, highpass reflectionless filter (2.9 to 8.7 GHz) is combined with a lowpass LTCC filter (DC to 10.6 GHz) to use the greater selectivity of the latter. Simulation results are shown in ***Figure 4a***, along with the FCC spectral mask for indoor UWB transmissions. This combination exhibits a passband from 2.4 to 10.9 GHz (4.5:1 or 128



▲ **Fig. 4** Simulated response combining XHF-292M+ and LFCW-1062+ vs. FCC spectral mask for UWB indoor transmissions (a), devices in the test fixture (b) and measured results (c).



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percent bandwidth). Deep rejection at the lower stopband, below 2.4 GHz, keeps transmissions at neighboring frequencies, such as GPS at 1.6 GHz, clean of emissions. While the data for the LTCC filter stops at 15 GHz, it is clearly approaching some re-entry at that point. This is a trade-off when incorporating a different filter technology.

The test board for this filter combination is shown in ***Figure 4b*** and the measured insertion loss is shown in ***Figure 4c***. It has a measured 3 dB passband from about 2.45 to 10.9 GHz (4.5:1 or 127 percent bandwidth), consistent with the simulation. The combination with the LTCC filter introduces a few noteworthy differences from the previous cases. First, the insertion loss suffers some re-entry around 25 GHz, enough to just cross the FCC limit. Also, the return loss in the upper stopband (not shown) degrades because the LTCC filter is fully reflective in its stopband. Overall, the filter approaches the desired response for real world UWB transmission, yet is still wider than ideal. A similar approach with the right combination of filters may come closer to the ideal filter behavior.

Case 5: UWB Filter Meeting the FCC Emission Mask for Indoor UWB Transmission

To realize a filter response closer to the ideal for real world UWB transmission, careful model selection leads to the combination of a three-section, highpass reflectionless filter (5 to 11 GHz) and a lowpass LTCC filter (DC to 8.4 GHz). A simulation of this filter combination is shown in ***Figure 5a***, including the FCC mask for indoor UWB transmission. The simulated 3 dB passband is from 3.9 to 9.4 GHz (2.4:1 or 83

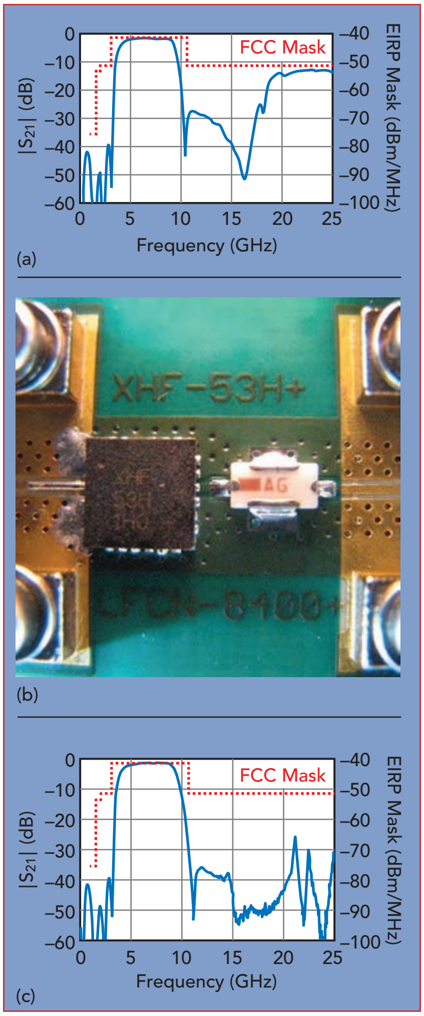

Fig. 5 Simulated response combining XHF-53H+ and LFCN-8400+ vs. FCC spectral mask for UWB indoor transmissions (a), devices in the test fixture (b) and measured results (c).

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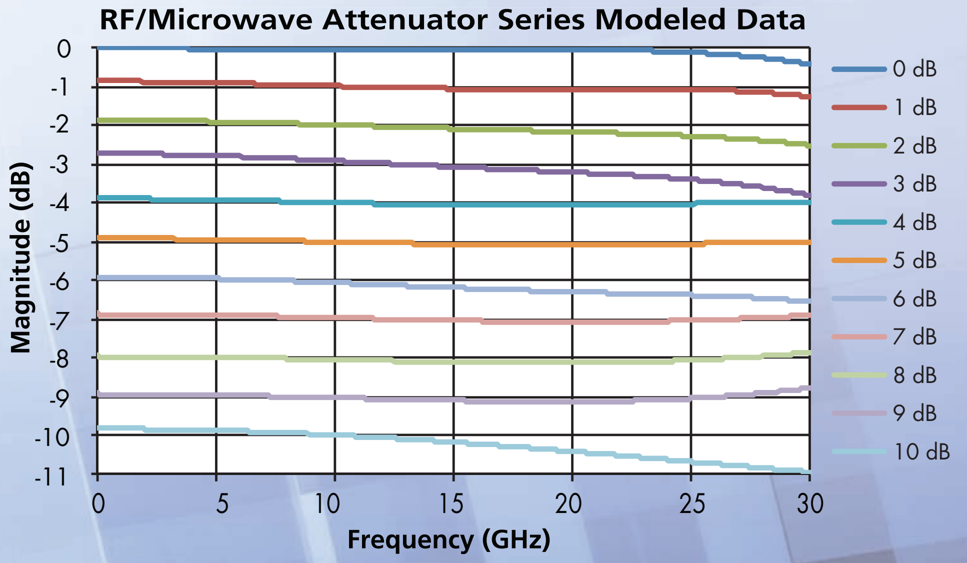

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THE ENGINEERS' CHOICE® www.atceramics.com percent bandwidth). Although the LTCC filter does show some re-entry in the upper stopband, it is not significant enough to become a secondary passband, remaining well below the FCC mask.

The test board is shown in ***Figure 5b*** and the measured insertion loss is in ***Figure 5c***. The filter response exhibits a 3 dB passband from 4.25 to 9.15 GHz (2.2:1 or 73 percent) and conforms well to the FCC spectral mask. Again, the reflectionless LTCC hybrid approach comes with some tradeoffs that warrant mentioning. First, as expected, the filter exhibits reflective behavior in the upper stopband and return loss degrades above 9 GHz. Secondly, while the upper stopband achieves excellent rejection to 25 GHz, it suffers some re-entry around 30 to 35 GHz. A different lowpass filter model may be needed to suppress this re-entry at higher frequencies. Nonetheless, this example illustrates how reflectionless filters can be successfully cascaded with other filter designs to achieve the desired passband shape for UWB communications.

CONCLUSION

The examples in this article show how reflectionless filters provide a novel and highly viable approach to filter design for UWB applications. They all employ standard, catalog filters available from Mini-Circuits. Mini-Circuits offers over 50 reflectionless filter models from stock, and custom designs are available to meet exact application requirements.

The approach demonstrated provides designers several practical advantages over previously studied approaches using microstrip structures. In addition to the electrical properties that make reflectionless filters ideal for UWB, the filters are smaller, less costly and more repeatable compared to competing technologies, making them suitable candidates for use in commercial applications where volume manufacturability may be a requirement.

Mini-Circuits is currently developing new designs with lowpass and highpass filter dice cascaded within a single package to reduce size, lower cost and minimize parasitic effects.

While this article discussed the suitability of reflectionless filters for UWB applications, it should serve to broaden the reader's understanding of these innovative products as flexible building blocks with numerous applications in RF system design, many of which still remain to be explored.■

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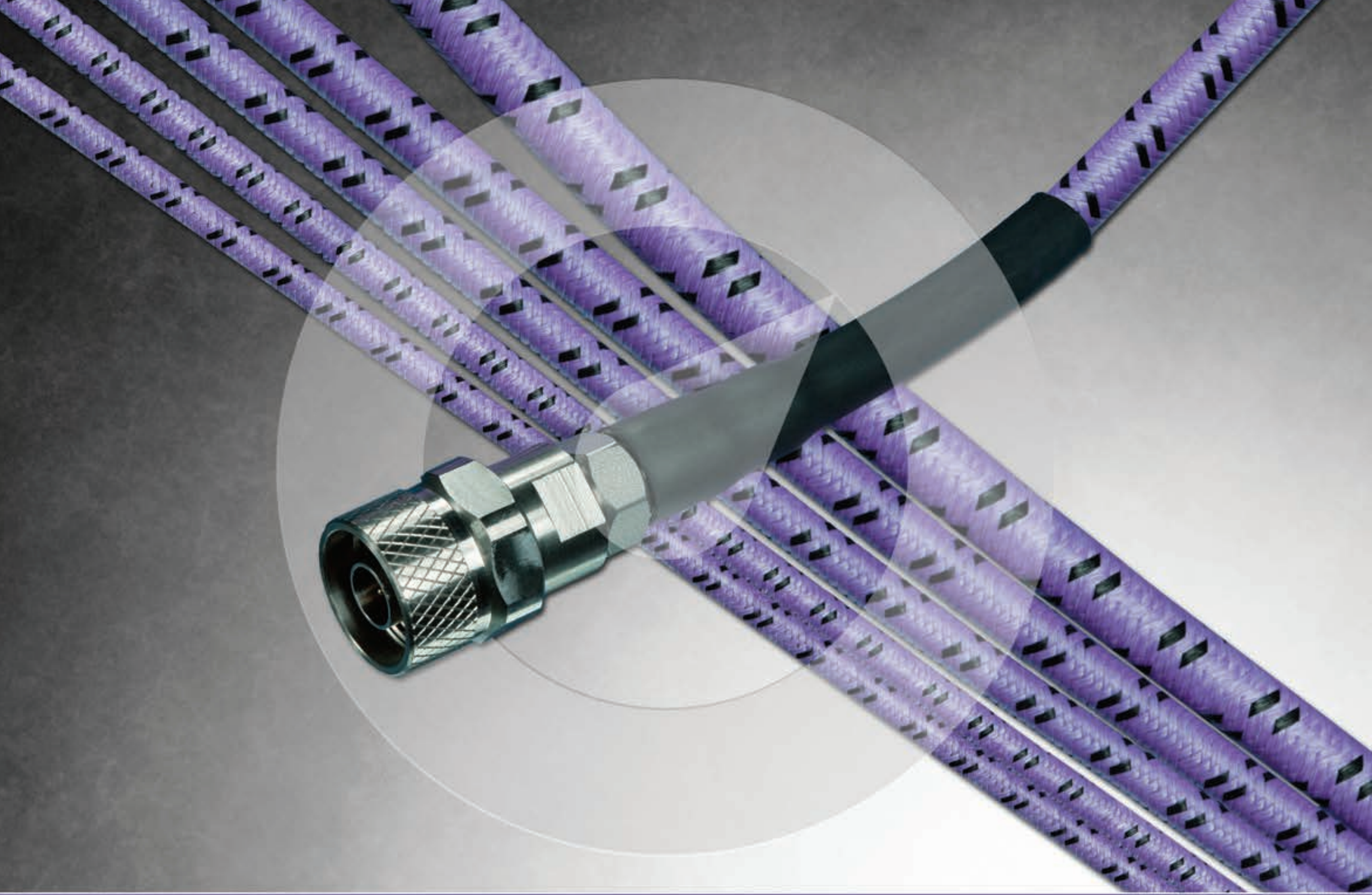

Time Domain Channel Compensation Suitable for Wideband Digital Predistortion

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In-phase/quadrature-phase (I/Q) errors in the implementation of a digital predistortion (DPD) system based on a direct-conversion structure have proven to be a limiting performance factor in modern communication systems. This work presents a method of time domain compensation (TDC) for frequency-dependent channel imbalances in wideband DPD systems. Compared with the widely used frequency domain compensation method, this method has lower computational complexity. Experimental results show that this method improves transceiver loop normalized mean squared error (NMSE) for 20 and 60 MHz Long Term Evolution (LTE) signals by 10.9 and 11.3 dB, respectively. Adjacent channel power ratio (ACPR) is improved by more than 6 and 8 dB, respectively.

The RF power amplifier (PA) is a major component in wireless communication systems; however, PA intermodulation distortion leads to signal errors and spectrum expansion. To solve the problem, both analog and digital predistortion have been employed.[1,2] DPD, with the advantages of convenient implementation, flexibility and adaptability, has become the preferred approach.

Figure 1 is a block diagram of a DPD system with an imperfect transceiver loop. Numerous DPD models have been presented,[3] but they do not consider the impact of I/Q imbalance in the transceiver. Anttila et al.[4] noted that I/Q imbalance seriously affects DPD performance, and they presented a new DPD structure for reducing I/Q imbalance in direct-conversion radio transmitters. Kim et al.[5] described a joint DPD method for compensating PA nonlinearity and I/Q imbalance; however, only frequency-independent I/Q imbalance was considered. Rampa[6] introduced a frequency-dependent I/Q imbalance compensation scheme, but considered only transmitter distortion. Rawat et al.[7] used a hybrid RF/DPD structure based on a lookup table to compensate for I/Q imbalance, but it needed a large amount of storage space.

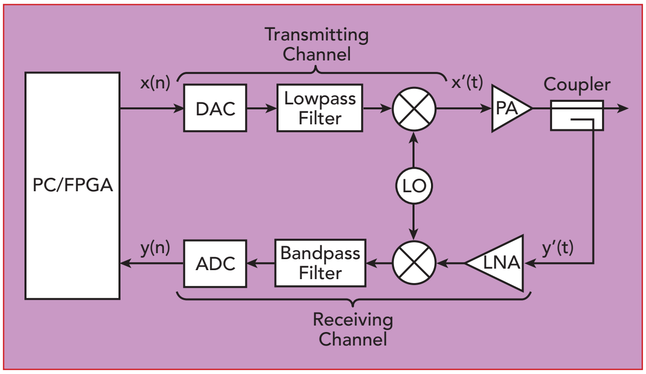

Fig. 1 DPD system with an imperfect transceiver loop.

In this work, we focus on PA nonlinearity and frequency-dependent I/Q imbalance in the implementation of a broadband DPD platform that compensates for imbalance from both the transmitter and receiver. Through measurements of the signal with different bandwidths, the method of TDC described here works well in systems with significant I/Q distortion.

NONLINEAR DISTORTION MODEL

Figure 2 shows the block diagram of a typical direct-conversion receiver to illustrate the following discussion of I/Q receiving channel imbalance model extraction and PA nonlinear modeling.

Channel I/Q Imbalance Model

Without loss of generality, the following derivation assumes that the I/Q imbalance is frequency independent. Also assume that the I/Q imbalance is caused by local

oscillator (LO) imbalance in the I/Q path. Figure 2 shows the baseband equivalent signal model for I/Q imbalance, which can be written as[1]

$$x_{LO}(t) = \cos(\omega_{LO}t) - j\alpha\sin(\omega_{LO}t + \varphi) \quad (1)$$

Using Euler's formula

$$x_{LO}(t) = \left(\frac{1}{2} + \frac{\alpha}{2}e^{j\varphi}\right)e^{-j\omega_{LO}t} + \left(\frac{1}{2} - \frac{\alpha}{2}e^{-j\varphi}\right)e^{-j\omega_{LO}t}$$

$$x_{LO}(t) = K_1 e^{-j\omega_{LO}t} + K_2 e^{j\omega_{LO}t} \quad (2)$$

$$\text{where} \begin{cases} K_1 = \dfrac{1+\alpha e^{-j\varphi}}{2} \\ K_2 = \dfrac{1-\alpha e^{j\varphi}}{2} \end{cases}$$

and α is the amplitude imbalance and φ is the phase imbalance.

Actually, Equation 2 takes into account the bandpass filter (BPF) imbalance as well. Assuming that the received signal is ideal, where $x_I(n)$ and $x_Q(n)$ are the real and imaginary parts, the complex baseband signal is

$$r(t) = x(t)e^{j\omega_{LO}t} = [x_I(t) + jx_Q(t)] [\cos(\omega_{LO}t) + j\sin(\omega_{LO}t)] \quad (3)$$

In the receiver, the ideal complex baseband signal through the BPF and mixer can be written as

$$\tilde{x}(t) = BPF\{x_{LO}(t) \otimes r(t)\} = K_1 x(t) + K_2 x^*(t) \quad (4a)$$

$$\tilde{x}(t) = x_I(t) + j[\alpha x_Q(t)\cos(\varphi) - \alpha x_I(t)\sin(\varphi)] \quad (4b)$$

and we have

$$\tilde{x}_I(t) = x_I(t)$$
$$\tilde{x}_Q(t) = -x_I(t)\alpha\sin(\varphi) + x_Q\alpha\cos(\varphi) \quad (5)$$

for which the matrix form is

$$\begin{bmatrix} \tilde{x}_I(t) \\ \tilde{x}_Q(t) \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\alpha\sin(\varphi) & \alpha\cos(\varphi) \end{bmatrix} \begin{bmatrix} x_I(t) \\ x_Q(t) \end{bmatrix} \quad (6)$$

If α and φ are extracted from Equation 1, the amount of compensation for the channel can be estimated. In most of the literature, compensation is done with a mirror image signal. Alternatively, we use digital pre-compensation in the I and Q paths.

PA Model Extraction

The nonlinear model of a PA is also key to DPD performance. However, because much has been writ-

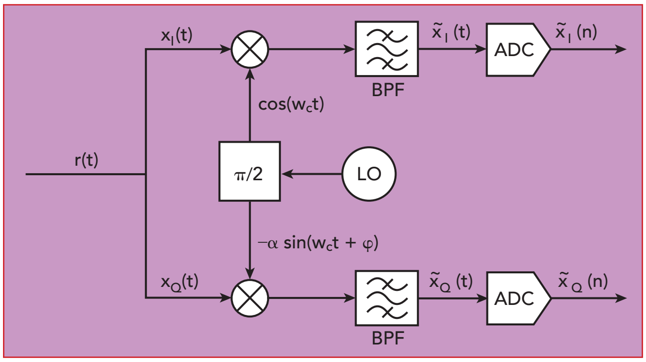

Fig. 2 Typical direct-conversion receiver.

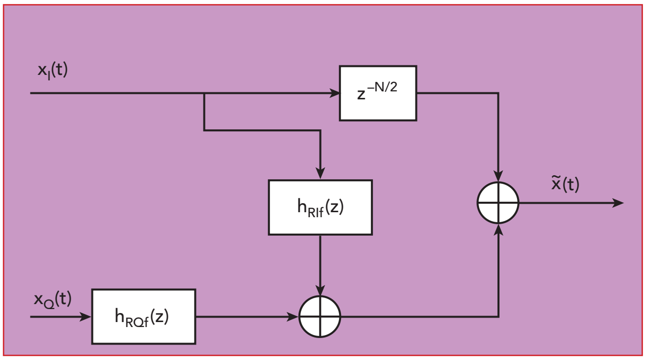

Fig. 3 Wideband compensation model for the receiver.

ten about this in the literature,[8-10] it is not the focus of our work. We use the first-order dynamic derivation reduction (DDR) model to describe PA nonlinearity, which can be written as

$$y(t)=\sum_{p=0}^{\frac{P}{2}}\sum_{m=0}^{M}\alpha_{2p+1,1}\left|x(m)\right|^{2p} x(n-m)+\sum_{p=0}^{\frac{P}{2}}\sum_{m=1}^{M}\alpha_{2p+1,2}\left|x(n)\right|^{2(p-1)} x^2(n)x^*(n-m) \quad (7)$$

where p denotes the order of nonlinearity and M is the memory length. x(n) and y(n) are the input and output of the PA, respectively. From Equation 7, the matrix form is

$$Y=A*X \quad (8)$$

where X is the PA input vector and Y is the PA output vector. A represents the coefficients vector of the PA, which can be obtained with the least squares algorithm. For example,

$$A=\left(X^H X\right)^{-1}X^H Y \quad (9)$$

CHANNEL COMPENSATION MODELING

Frequency-dependent I/Q imbalance is modeled to compensate for an imperfect channel. I/Q imbalance compensation modeling is separated for the receiver and transmitter channels.

Receiver Channel Compensation Model

In the receiver, TDC amplitude and phase for the wideband channel are extracted by constructing an orthogonal and cyclically symmetric signal. Wideband time domain modeling is performed by using compensation values for different frequency bands. The real and imaginary parts of the test signal satisfy

$$\begin{cases}E\{x_I(t)x_Q(t)\}=0\\ E\{x_I^2(t)\}=E\{x_Q^2(t)\}\end{cases} \quad (10)$$

which, according to Equation 5, can be written as

$$\begin{cases}E\{\tilde{x}_I^2(t)\}=E\{x_I^2(t)\}\\ E\{\tilde{x}_Q^2\}=\alpha^2E\{x_Q^2(t)\}\\ E\{\tilde{x}_I(t)\tilde{x}_Q(t)\}=-\alpha\sin\varphi E\{x_I^2(t)\}\end{cases} \quad (11)$$

from which we obtain the following expression for the compensation coefficients:

$$\begin{cases}\alpha=\sqrt{\dfrac{E\{\tilde{x}_Q^2(t)\}}{E\{\tilde{x}_I^2(t)\}}}\\ \varphi=-\arcsin\dfrac{E\{\tilde{x}_I(t)\tilde{x}_Q(t)\}}{\sqrt{E\{\tilde{x}_I^2(t)\}E\{\tilde{x}_Q^2(t)\}}}\end{cases} \quad (12)$$

where E{} is the mathematical expectation signal. After obtaining α and φ, we solve the inverse matrix of Equation 13 to obtain a frequency-independent TDC expression for the receiving channel.

$$\Psi=\begin{bmatrix}1 & 0\\ \tan\varphi & \dfrac{1}{\alpha\cos\varphi}\end{bmatrix} \quad (13)$$

The wideband compensation model (see ***Figure 3***) can be regarded as a combination of the corresponding compensation coefficients for each frequency point. From Figure 3, the expression for compensation can be written as

$$\tilde{x}(t)=x_I(t)+j\left(h_{RQf}(z)\otimes x_Q(t)+h_{RIf}(z)\otimes x_I(t)\right) \quad (14)$$

where $h_{RIf}(z)$ and $h_{RQf}(z)$ are the I/Q channel compensation functions. They are implemented using a finite impulse response (FIR) structure. In Figure 3, the $z^{-N/2}$ block eliminates the delay of the I and Q paths, and N represents the FIR order.

Transmitting Channel Compensation Model

Because the imbalance of the transmission channel is caused mainly by the physical circuit, external interference is very small. Therefore, the imbalance of the

transmit channel is much flatter than that of the receiving channel. In order to compensate for a wideband transmit signal, we use a derivation based on polar coordinates (see ***Figure 4***).

Assume the I path offset angle is φ. From ***Figure 5***, the relationship of $\tilde{x}_I$ and $\tilde{x}_Q$ (compensated output) with the ideal input signal is

$$\tilde{x}_I = x_I \times \cos(\varphi)$$
$$\tilde{x}_Q = x_Q - x_I \times \sin(\varphi) \qquad (15)$$

Extended to a frequency-dependent compensation expression,

$$\tilde{x}_I = x_I \otimes h_{SIf}\left(\cos(\varphi)\right)$$
$$\tilde{x}_Q = x_Q - x_1 \otimes h_{SQf}\sin(\varphi)) \qquad (16)$$

where $h_{SIf}(z)$ and $h_{SQf}(z)$ are the I/Q channel compensation functions. They are implemented using a FIR structure. The $z^{-N/2}$ block eliminates

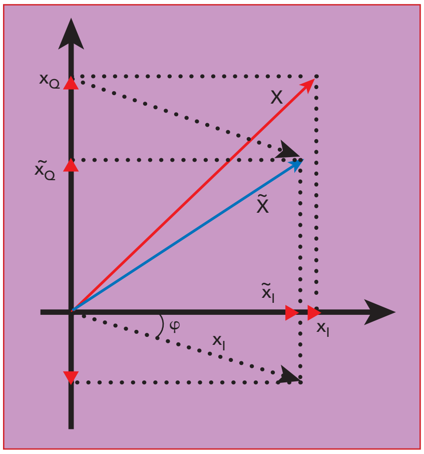

Fig. 4 Polar coordinate model for transmitter channel compensation.

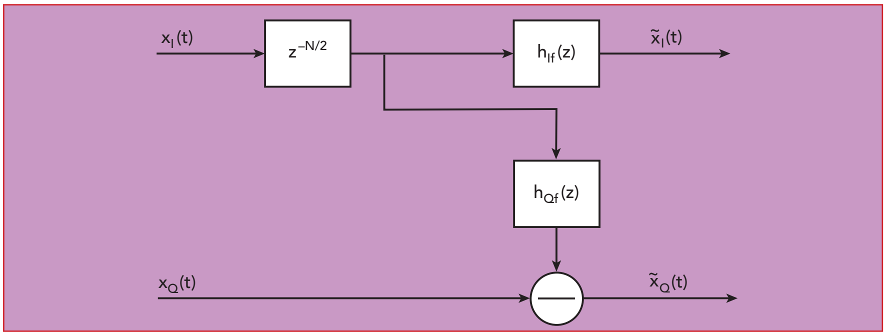

Fig. 5 Wideband compensation model for the transmitter.

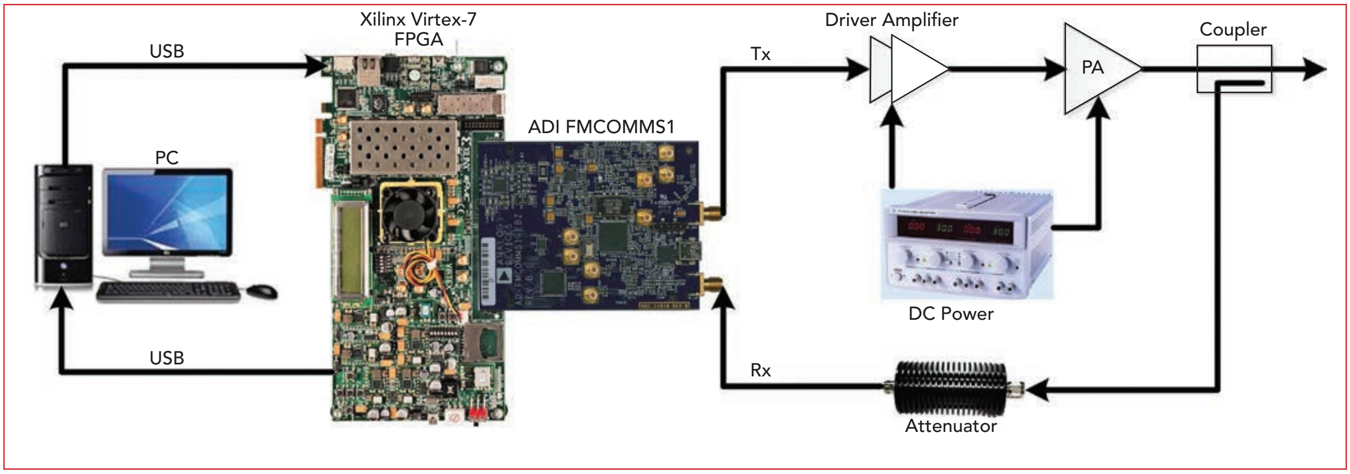

Fig. 6 Software and hardware architecture of the DPD platform.

the delay of I and Q paths, where N represents the order of FIR. Compensation is performed in the baseband I and Q paths.

VALIDATION AND EXPERIMENTAL RESULTS

First, the compensation effect of the transceiver channel was verified, followed by verification of the DPD effect on the signal before and after transceiver channel compensation. ***Figure 6*** shows the software and hardware architecture of the DPD platform. Validation used 20 MHz single-carrier and 60 MHz three-carrier LTE signals with peak-to-average power ratios (PAPR) of 7.25 and 9.29 dB, respectively. All original signals generated in MATLAB were fed to the PA through an FPGA.

A PA designed with a Wolfspeed (Cree) CGH40010 transistor was used for the device under test. The PA was biased with V_{GS} = -2.7 V and V_{DS} = 28 V, placing the amplifier in class AB mode of operation. The PA was driven to saturation with a peak output power of 40 dBm. The operating frequency band was 1.7 to 2.6 GHz, with DPD validation at 2.4 GHz.

The DPD platform consisted of a Xilinx Virtex-7 FPGA on an ADI RF board. The digital-to-analog converters (DAC) and analog-to-digital converters (ADC) had 16- and 14-bit resolution, respectively. The maximum sample rate of the ADC was 250 MSPS, and the maximum sample rate of the DAC was 1 GSPS.

Effect of Loop Compensation

AM/AM and AM/PM are used to characterize channel memory and nonlinearity. To verify the channel compensation model, the 20 and 60 MHz signals are used to test nonlinearity and memory level with and without the channel compensation model. Measured results for the AM/AM and AM/PM characteristics of the channel are shown in ***Figure 7***.

I/Q transceiver channel imbalance causes significant signal amplitude and phase distortion in an uncompensated channel. With increased bandwidth, imbalance and resulting distortion are greater. The compensation scheme effectively reduces this distortion. ***Table 1*** compares NMSE performance with and without compensation, showing improvements of 10.9 and 11.3 dB, respectively, for the 20 and 60 MHz LTE signals.

DPD Measurement Results

In general, DPD performance depends on the quality of the model and the accuracy of the parameter extraction process. The TDC model described extracts the PA output signal accurately. To verify that it is suitable for wideband DPD, two sets of measurements were made.

Without loss of generality, the measurements were made using the first-order DDR model. Memory depth and nonlinear order number were consistent in the measurements to objectively demonstrate the advantages of the model. ***Figure 8a*** shows the results of PA linearization for 20 MHz single-carrier LTE signals. It can be seen that the TDC model has good adaptability to frequency-dependent I/Q imbalance, resulting in better linearization performance in terms of ACPR at the output of the PA. ***Figure 8b*** shows the results of PA linearization for 60 MHz three-carrier LTE signals. With the increased bandwidth, the I/Q channel is more sensitive to DPD performance. ***Table 2*** shows measured ACPR performance for the two bandwidths.

CONCLUSION

Wideband channel compensation is becoming more important in communications systems. In this paper, a method of TDC for frequency-dependent channel imbalance in wideband DPD systems is described using the FIR structure in FPGA hardware. Better than 6 and 8 dB ACPR improvement was achieved with 20 and 60 MHz LTE signals, respectively, compared to performance without channel compensation.■

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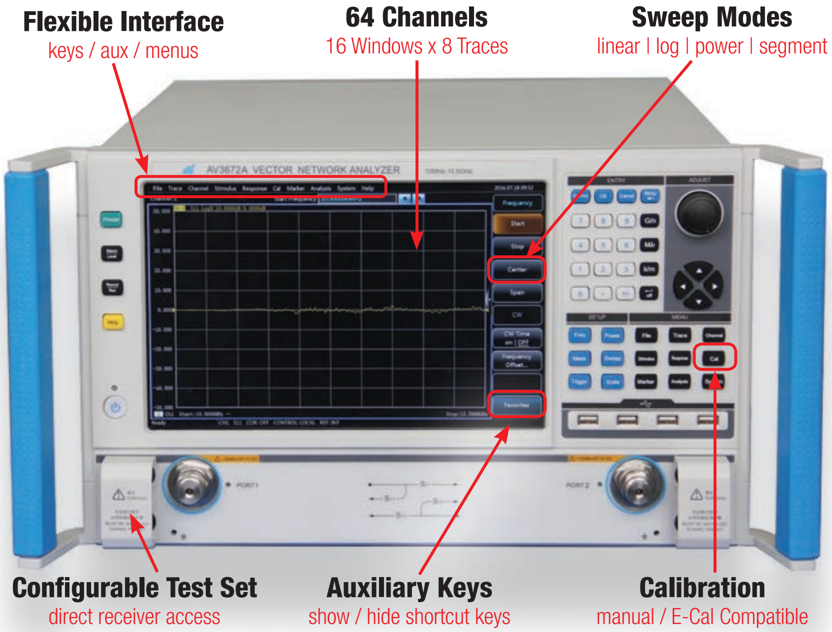

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TABLE 1

NORMALIZED MEAN SQUARED ERROR PERFORMANCE

	NMSE (dB)	
	Without Compensation	With Compensation
20 MHz LTE	-26.72	-37.70
60 MHz LTE	-19.12	-30.43

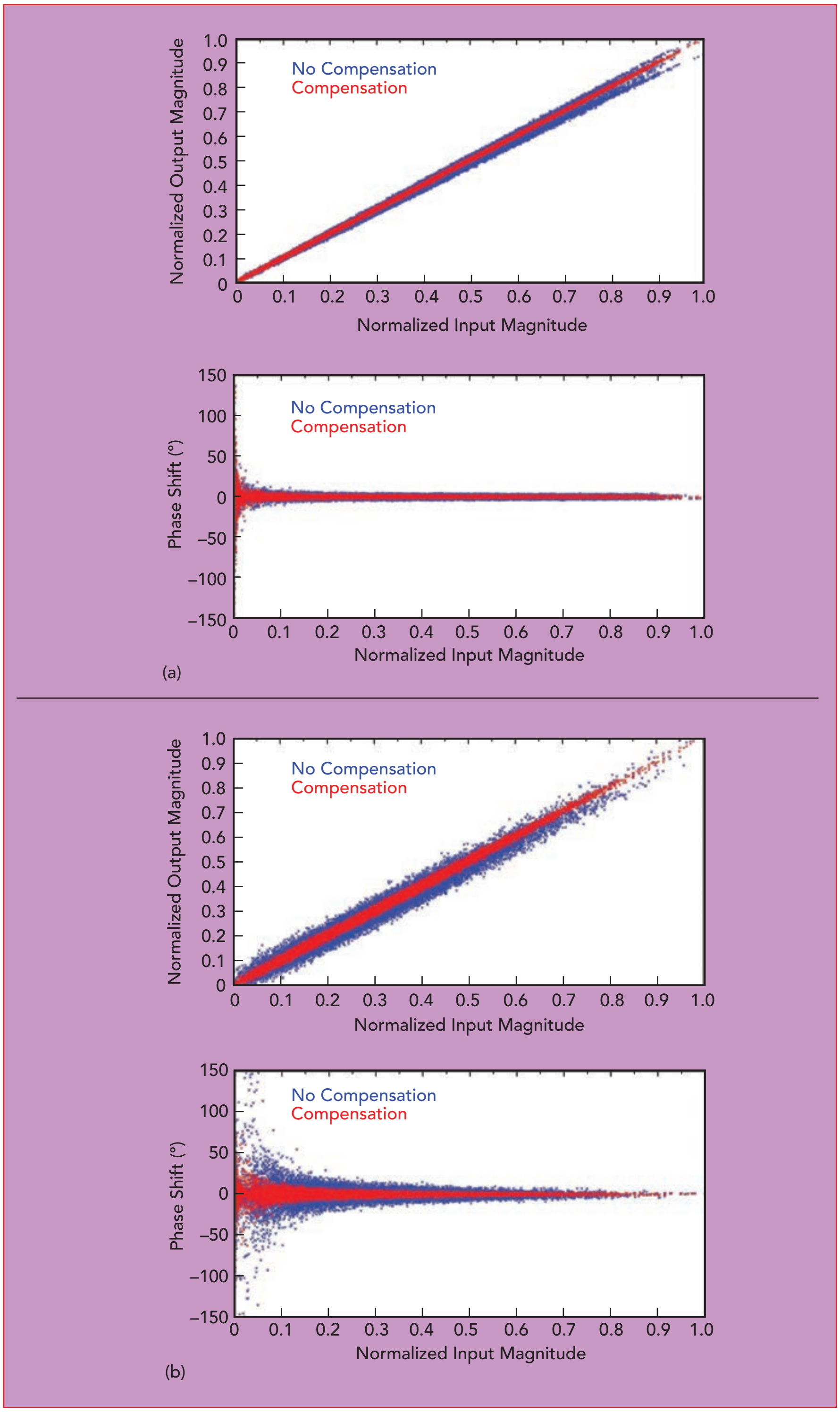

Fig. 7 Measured AM/AM and AM/PM for 20 MHz single-carrier (a) and 60 MHz three-carrier (b) LTE signals.

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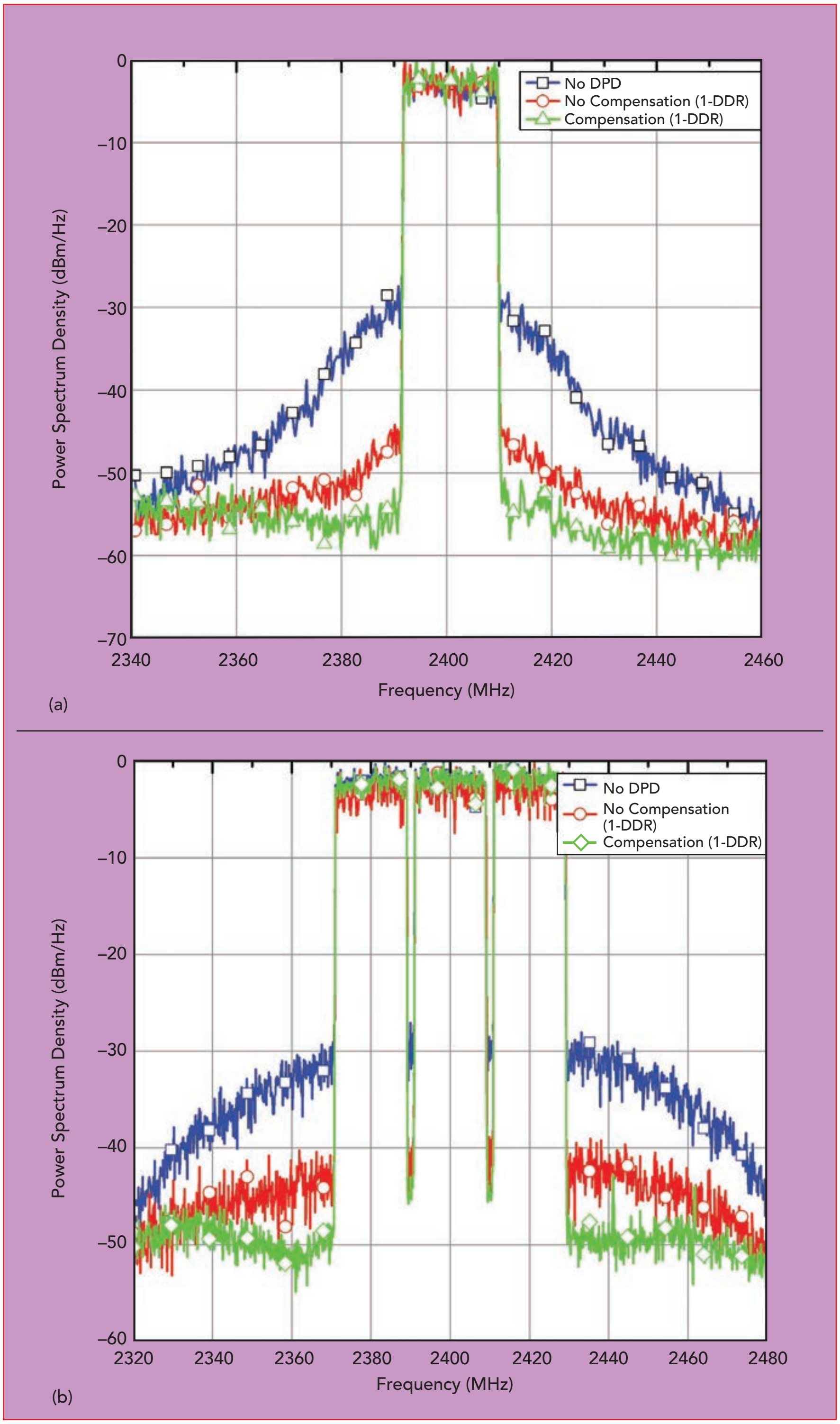

▲ Fig. 8 Measured PA output spectrum for 20 MHz single-carrier (a) and 60 MHz three-carrier (b) LTE signals.

TABLE 2
WIDEBAND DPD PERFORMANCE WITH PA

		No DPD	No Compensation (1-DDR)	With Compensation (1-DDR)
ACPR (dB)	20 MHz	-30.56/-31.58	-47.60/-47.49	-53.95/-53.13
	60 MHz	-30.68/-29.18	-40.68/-39.19	-48.46/-47.81

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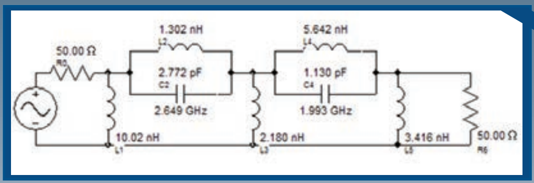

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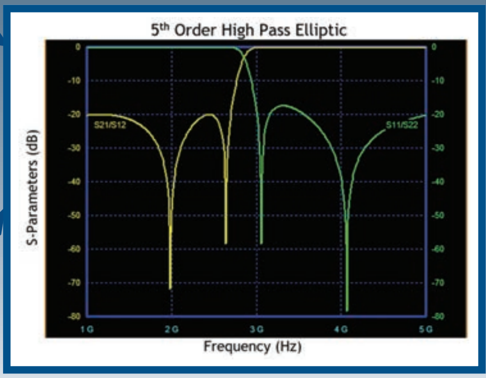

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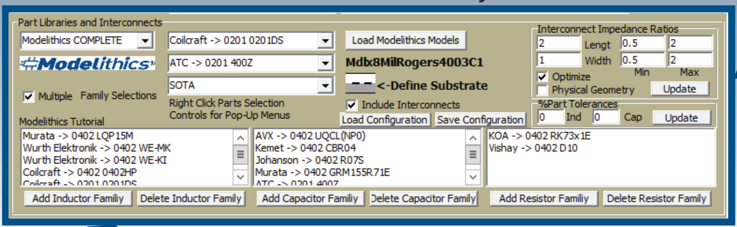

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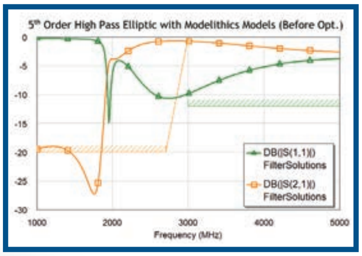

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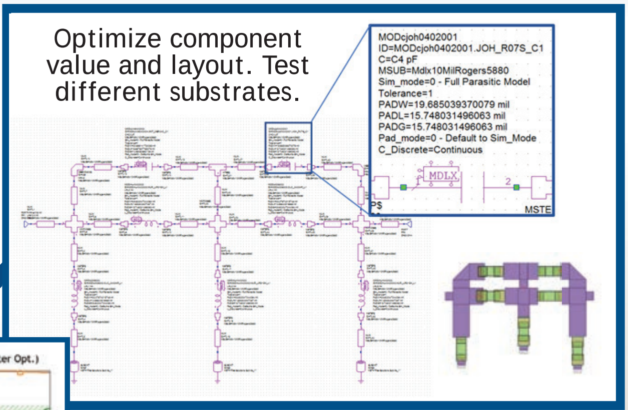

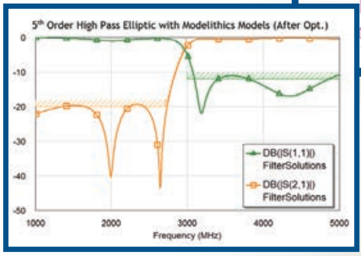

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Two-Layer Stacked Microstrip Cylindrical Conformal Antenna Array With Cross Snowflake Fractal Patches

Lei Xin, Kaiyuan Cao and Xiaoqing Yang
Sichuan University, Chengdu, China

A novel, two-layer, stacked, high gain, microstrip, cylindrical conformal antenna based on planar cross snowflake fractal patches exhibits high gain and aperture efficiency. Its impedence bandwidth is 19.75 percent, from 5.23 to 6.54 GHz, with a gain of 12.1 dBi and its corresponding aperture efficiency is 87.5 to 89.75 percent at 5.8 GHz. Measurement results agree closely with the simulation.

Conformal antennas have received wide interest in aerospace and wireless communication applications due to their aerodynamic properties and low radar cross section (RCS).[1-2] Characteristics such as small volume, light weight and low profile, make the microstrip antenna a preferred choice.[3] When conformed to a curved surface geometry, however, its electromagnetic properties and corresponding radiation patterns are strongly disturbed; the influence of mutual coupling and feed phase cannot be neglected.[4-5] The problem of overcoming performance deficiencies in conformal antennas, with respect to array unit and aperture efficiency, has been well studied, with much theoretical analysis.[6-16] The conformal finite difference time domain (CFDTD) method[6] and discrete mode matching method (DMM)[7-8] are often used to investigate and improve the electromagnetic properties of cylindrical conformal antennas.

Specific structures proposed to improve conformal antenna characteristics include the helix, meander-line and electromagnetic band gap (EBG).[17-20] By combining the helix antenna and meander-line antenna, a broad bandwidth hybrid antenna with high radiation efficiency is realized.[17] Use of an EBG achieves miniaturization with high gain.[18] In this article, a novel, two-layer, stacked, high gain, microstrip, cylindrical conformal antenna based on planar cross snowflake fractal patches is described.[21] Its parameters are optimized using the 3D full-wave finite element method (FEM). The influence of several factors on performance is analyzed, and both simulated and experimental results are presented.

ANALYSIS AND SIMULATION

As demonstrated by Jin et al.,[21] a microwave planar antenna with 2 × 2 cross snowflake radiators demonstrates promising performance, such as high gain and aperture efficiency at its center frequency of 5.8 GHz. Its impedance bandwidth, defined as $|S_{11}| <$ -10 dB, is 22.9 percent, gain is as high as 12 dBi and its corresponding aperture efficiency is as much as 87.4 percent. Compared with rectangular array elements, the cross snowflake fractal antenna array reduces the required aperture size by 51 percent. The work described here uses the 2 × 2 cross snowflake fractal pattern antenna in a cy-

lindrical conformal array to achieve high gain and aperture efficiency.

The sizes of the 2 × 2 cross snowflake radiators and cylindrical cavity can be determined based on a conventional two-layer, stacked, microstrip antenna array panel, as shown in ***Figure 1***.[21] The outer surface of a cylindrical cavity is fitted onto the parasitic layer, and the inner surface is fitted onto the radiation layer, forming a cylindrically shaped body. The geometric parameters and values of the conformal antenna design are shown in ***Table 1***. The dimensions of the conformal antenna are given by

$$R_1 = L \times b \times n$$
$$R_2 = L \times n$$
$$L_s = 2 \times (D + L)$$
$$X = (D - L_0 - W_1)/2$$
$$L_t = (D + L - W_2)/2,$$
$$L_3 = (D + L) - 2 \times (L_1 + L_2) - W_1$$

The initial size, L, of the single element square patch is obtained by

$$L = \frac{\lambda_0}{2\sqrt{\varepsilon_r}} = \frac{c}{2f_0\sqrt{\varepsilon_r}} \quad (1)$$

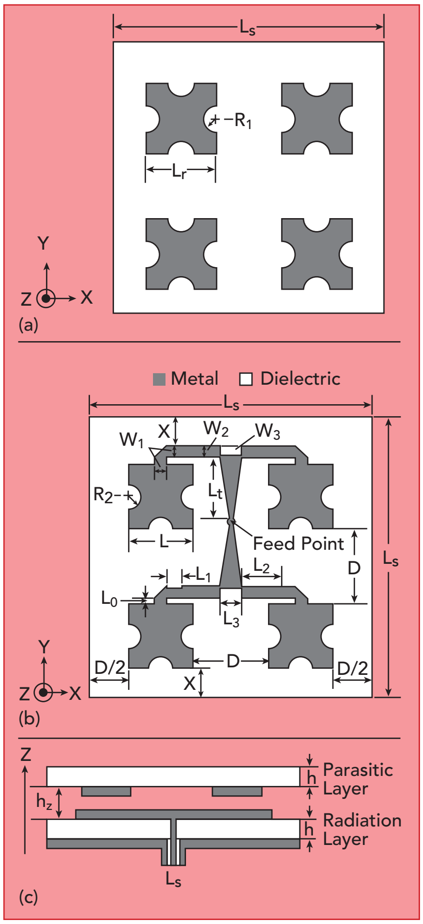


Fig. 1 Stacked microstrip antenna array structure: parasitic layer (a), radiation layer (b), cross section (c).

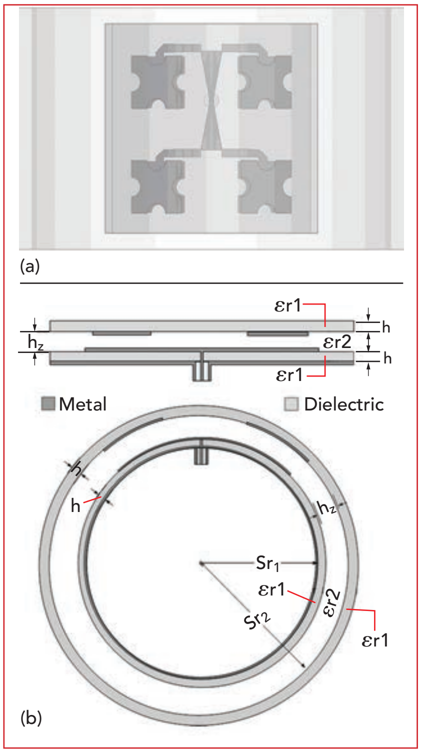


Fig. 2 Top (a) and front (b) views of cylindrical conformal antenna.

TABLE 1

CONFORMAL ANTENNA DESIGN

Parameter	(mm)
D	17.71
L	18.02
L_0	0.81
L_1	1.43
L_2	9.25
W_1	2.65
W_2	2.04
W_3	0.83
L_r	16.14

TABLE 2

OPTIMIZED PARAMETERS

ε_{r1}	2.65
ε_{r2}	1
h	0.25 mm
h_z	2.35 mm
S_{r1}	63 mm
S_{r2}	S_{r1} + h
b	1.05
n	0.19

where λ_0 is the free-space wavelength, c is the velocity of light in free space, ε_r is the relative dielectric constant of the substrate and f_0 is the center frequency of the antenna.

Based on the structure of the cylindrical conformal antenna, the original size of the panel antenna[21] is adjusted and each parameter is optimized. Both the conformal antenna and the panel antenna realize the function of the coaxial feed with SMA connectors. Since the thickness of the layers directly affects the conformal profile and the thickness of the PTFE dielectric plate can make it difficult to bend with a relatively small radius, a dielectric plate with a thickness of 0.25 mm was chosen. Top and front views of the conformal structure are shown in ***Figure 2***. The ratio of the upper and lower side patch unit is b, the fractal ratio is n, the inner diameter of cylinder is S_{r1}, the height of the air is h_z, the permittivity of the layers is ε_{r1}, the dielectric permittivity of the air is ε_{r2} and the layer thickness is h. The optimized parameters are summarized in ***Table 2***.

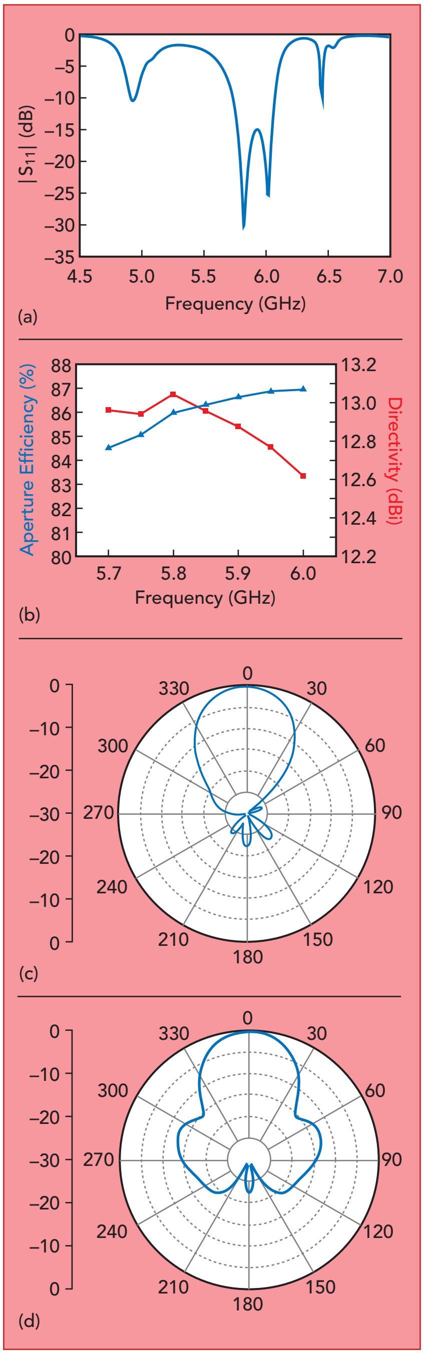


Fig. 3 Computer simulation of conformal antenna $|S_{11}|$ (a), directivity and aperture efficiency (b) vs. frequency and E-plane (c) and H-plane (d) patterns at 5.8 GHz.

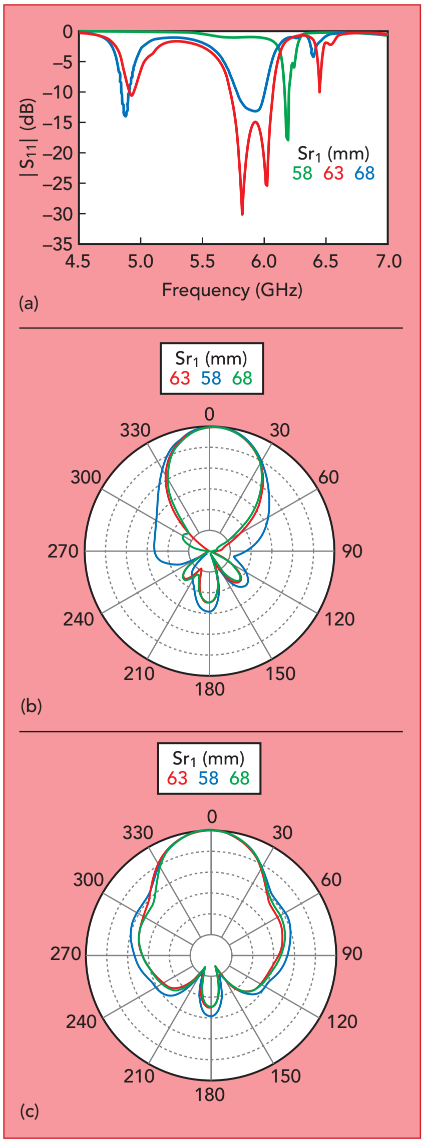
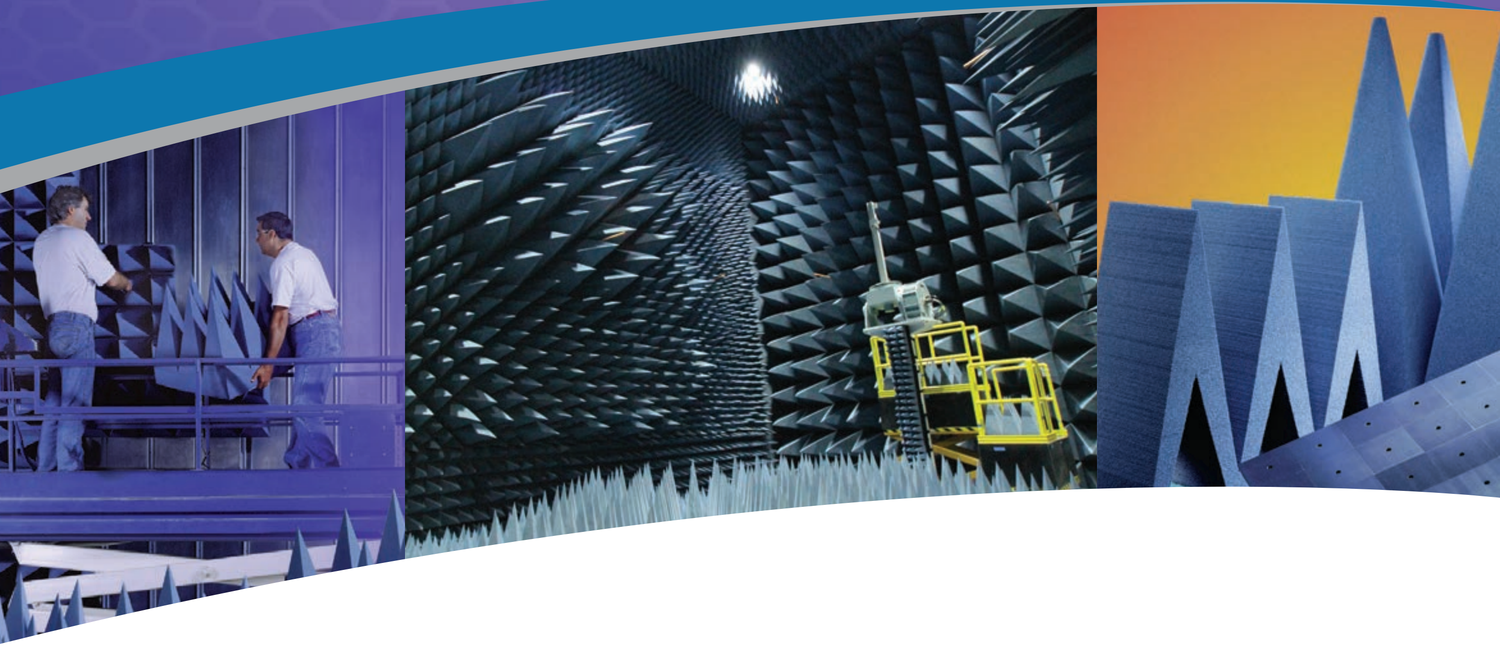


Fig. 4 Influence of the cylindrical radius on $|S_{11}|$ (a), E-plane (b) and H-plane (c) antenna patterns.



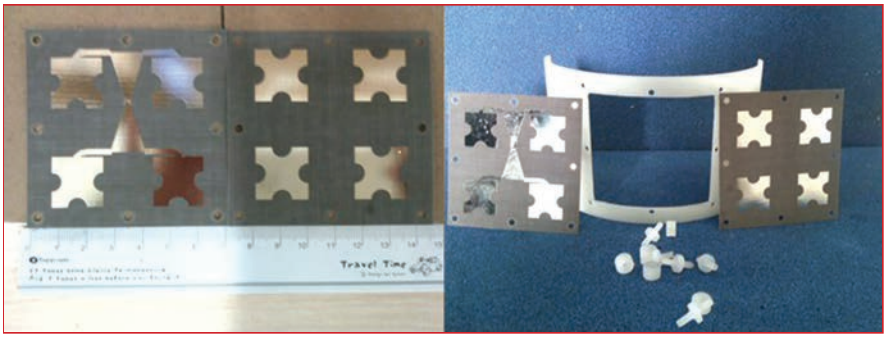


Fig. 5 Prototype conformal antenna.

Computer simulations of $|S_{11}|$, aperture efficiency, directivity and the radiation patterns in the E- and H-planes are shown in ***Figure 3***. At 5.8 GHz, the gain is 12.95 dBi and the aperture efficiency is 86.75 percent. The impedance bandwidth is 340 MHz, i.e., $|S_{11}| < -10$ dB from 5.73 to 6.07 GHz. Directivity is between 12.77 and 13.07 dBi, and aperture efficiency is between 83.34 and 86.75 percent.

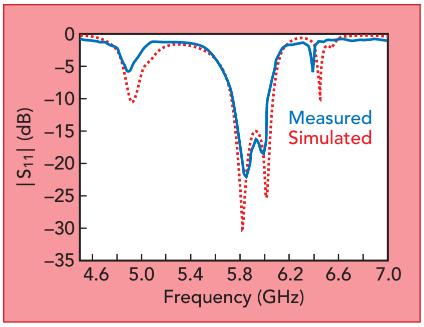


Fig. 6 Measured vs. simulated $|S_{11}|$.

SENSITIVITY ANALYSIS

To evaluate the robustness of the design, the influence of factors affecting the stability of antenna performance was explored: the radius of the cylinder, the dielectric constant and the spacing of layers. ***Figure 4*** shows the variation of $|S_{11}|$ and the antenna radiation patterns with the radius of cylinder S_{r1} at 58, 63 and 68 mm. With decreasing radius, the center frequency increases, accompanied by a sharp decline in impedance bandwidth. With increasing radius, the impedance bandwidth is affected to a lesser degree. When the radius is 58 mm, its impact on the pattern, especially in

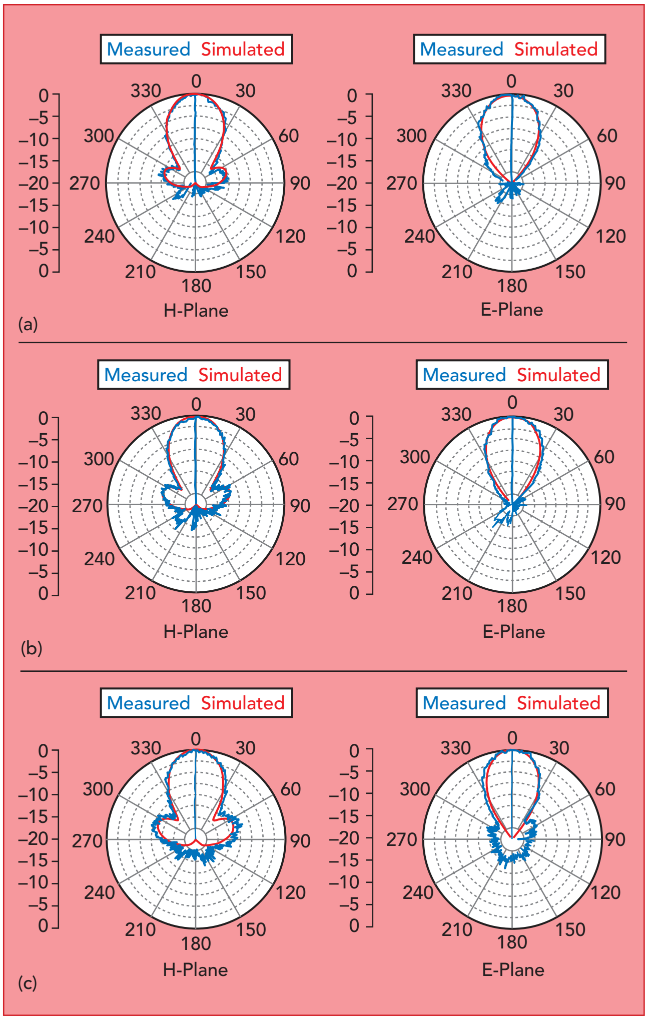


Fig. 7 Measured vs. simulated antenna patterns at 5.7 (a), 5.8 (b) and 5.9 (c) GHz.

the E-plane, is large; the side lobe and back lobe grow significantly. For a radius of 68 mm, the impact on the pattern is relatively small.

The dielectric constant of the teflon dielectric plate changes with frequency and temperature. The influence of dielectric constant on antenna performance was evaluated for ε_r values of 2.05, 2.55 and 3.05. The corresponding antenna gains are 13.6, 13.7 and 13.4 dBi, indicating the dielectric constant has little influence on the pattern. For a double-layer antenna, the spacing between the parasitic layer and radiation layer has a strong influence on impedance bandwidth but little influence on operating frequency. Radiation patterns with different layer spacing show that with hz spacings of 2.05, 2.35 and 2.65 mm, antenna gains are 12.3, 12.95 and 12.46 dBi, respectively, indicating that variation in the spacing of layers over a narrow range has little influence on gain.

EXPERIMENTAL RESULTS

The prototype antenna is shown in ***Figure 5***. Its reflection coefficient $|S_{11}|$ was measured with a vector network analyzer, and a comparison of the measured and simulated results is shown in ***Figure 6***. They are in good agreement, demonstrating an impedance bandwidth of 320 MHz ($|S_{11}| < -10$ dB from 5.73 to 6.05 GHz). Antenna patterns were measured at 5.7, 5.8 and 5.9 GHz (see ***Figure 7***). They agree well with the simulation, especially at the center frequency of 5.8 GHz.

CONCLUSION

This article describes a novel, two-layer, stacked, microstrip, cylindrical conformal antenna using cross snowflake fractal patches. Based on the planar cross snowflake fractal patches, the structure of the conformal antenna was optimized by FEM to achieve high aperture efficiency and wideband properties at a center frequency of 5.8 GHz. The measured impedance bandwidth extended from 5.23 to 6.54 GHz (19.75 percent). The gain was 12.1 dBi, and the corresponding aperture efficiency was between 87.5 and 89.75 percent.■

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Oscilloscopes Capture Longer Time Periods

Rohde & Schwarz
Munich, Germany

Engineers rely on oscilloscopes as a primary tool for testing and debugging electronic designs. Development teams need oscilloscopes that capture data over long time periods, have increased vertical resolution, incorporate increased functionality, are easy to operate and fit within constrained budgets. To address these needs, Rohde & Schwarz has introduced the R&S RTM3000 and R&S RTA4000 series of oscilloscopes, complementing the R&S RTB2000 series introduced in 2017. Models are available in bandwidths ranging from 100 MHz to 1 GHz.

Two key attributes setting these new oscilloscopes apart is their deeper memory and increased vertical resolution.

MEMORY

Acquisition memory determines how much time an oscilloscope can capture. Typically oscilloscopes comparable to the R&S RTM3000 and R&S RTA4000 have an acquisition memory between 4 and 20 Msample; some do not offer segmented memory. For the design of the two new oscilloscopes, a different approach was taken to incorporate significantly more memory for capturing events that take longer, such as power-up and power-down sequences.

R&S RTM3000 models come with a 40 Msample acquisition memory standard (80 Msamples interleaved), while the R&S RTA4000 models come with 100 Msamples standard (200 Msample interleaved). Increased acquisition memory sizes allow engineers to retain fast sample rates while capturing longer time periods.

Segmented memory is a mode where the user partitions the acquisition memory into multiple segments. On each trigger event, the oscilloscope captures a certain amount of data around the trigger event. The R&S RTA4000 oscilloscope comes standard with 1 Gsample segmented memory, while the R&S RTM3000 models have a segmented option with 400 Msample memory. Segmented memory can be particularly useful for bursty signals, such as serial buses or RF communications, as no memory is used during periods of signal inactivity.

RESOLUTION

Low noise coupled with additional vertical resolution enables oscilloscopes to see signal details missed by other oscilloscopes. Both the R&S RTM3000 and the R&S RTA4000 series incorporate a 5 GSPS sample rate enabled by proprietary 10-bit analog-to-digital converters (ADC). Ten-bit ADCs have 1024 quantization levels, 4× more than the 256 quantization levels associated with traditional 8-bit ADCs.

Both new oscilloscope series feature a low noise front-end that retains full oscilloscope bandwidth down to 1 mV/div sensitivity. The additional signal detail is useful for applications such as power electronics and power integrity measurements, where users need to see small signal changes.

OTHER FEATURES

Both instrument series feature a bright 10.1 in. capacitive touch screen display that facilitates quick and efficient operation. They are highly portable and offer a boot-up time of 10 s. Each model includes a LAN interface enabling users to simply type the oscilloscope's IP address in a web browser to get screenshots, show the live scope display and control the front panel, with full standard commands for programmable instruments (SCPI) control from the browser.

Having the right probe is critical for most applications, particularly power electronics. The new oscilloscopes support a wide variety of passive and active probes, current and voltage probes and single-ended and differential probes, including four new R&S RT-ZHD high voltage differential probes. The new CAT III high voltage differential probes come in either 100 or 200 MHz bandwidth, allow input voltages to 6000 V, provide up to 2000 V offset compensation and have a high common-mode rejection ratio of 80 dB from DC to 60 Hz.

The oscilloscopes incorporate the USB-based standard media transfer protocol, the same standard that allows mobile phones to connect to PCs. It enables users to easily retrieve the oscilloscope's current display or export waveform data for post analysis (e.g., using Excel). The USB connection is located on the rear of the scope.

The new oscilloscope series offers users a variety of tools to assist in testing and debugging. These include a fast Fourier transform (FFT), allowing time-correlated time and frequency domain measurements (see ***Figure 1***), mask testing, XY mode, a DC meter and frequency counter.

Fig. 1 The oscilloscopes include an FFT, allowing time-correlated time and frequency domain measurements.

Not only are the oscilloscopes highly capable, users also have access to additional instrument functionality built into the products. There are: protocol triggering and decode options for I^{2}C, SPI, UART, RS-232, LIN, CAN, MIL-STD 1553, ARINC 429 and I^{2}S; an MSO option that adds 16 digital channels; a waveform generator for signal creation; a 4-bit pattern generator; power analysis; and a spectrogram option for viewing time-varying RF signals, such as signal hopping (see ***Figure 2***).

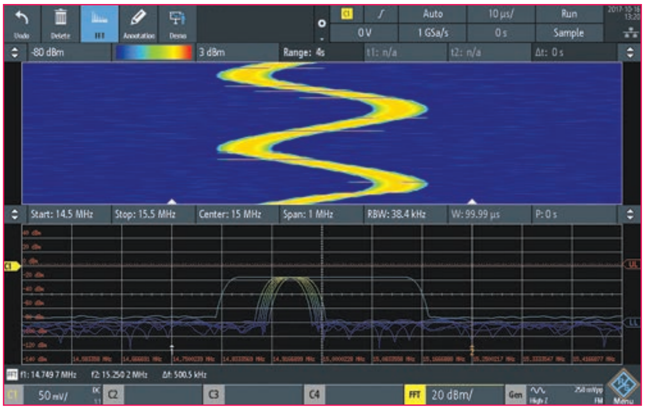

Fig. 2 A spectrogram option enables viewing time-varying RF signals, such as hopping.

VENDORVIEW

Rohde & Schwarz
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Integrating Design and Test Workflow

Keysight Technologies Inc.
Santa Rosa, Calif.

You, as engineers, are masters of efficiency. Your design teams use simulation software to save time before building working prototypes. Your test teams move from benchtop to modular to save space and gain performance. You search for the best international talent. All in the name of efficiency!

Yet, you spend hours correlating measurements from separate workflows. You program data into different software, two or three times. You write workarounds because your hardware and software do not natively talk to each other. You rely on your IT team to produce the analytics necessary to make decisions on your design of experiments. Why, in this connected, almost 5G world, are your product development teams still working with siloed datasets and disconnected workflows—with high risk of errors?

Why? Because, until now, an integrated and connected solution was not available. Now, you can take advantage of the technology of the future and integrate your design and test workflow with Keysight PathWave.

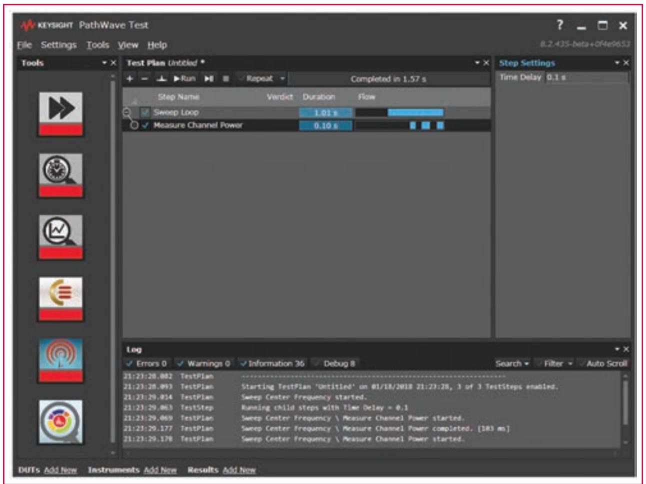

Fig. 1 PathWave Test provides an environment for launching a portfolio of measurement, test automation and data management tools.

WHAT IS KEYSIGHT PATHWAVE?

PathWave is an open, scalable and predictive software platform that integrates hardware and software at each stage in the product development workflow. It combines design software, instrument control and application-specific test software in an open development environment, allowing you to quickly create high performance solutions.

The PathWave software platform provides flexible and immediate access to the design and test tools you need, when you need them. Interoperability of the design and test tools and advanced data management significantly speeds the product development cycle, eliminating the need to recreate individual measurements and test plans at each discrete stage of the process. You


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34 GHz for RF 141
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Bend radius: 1/16 inch for RF 085
1/8 inch for RF 141
Max RF Power
20°C at Sea Level
RF .141
RF .085
700
660
200
160
120
80
40
0
4 8 12 16 20 24 28 32 36 40 44 48 52 56 60
Frequency (GHz)
Attenuation in dB/ft
RF .141
RF .085
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1.6
1.2
0.8
0.4
0.25
0.0
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Fig. 2 PathWave Analytics has built-in algorithms to predict downtimes and mitigate the risk of failure.

can be confident in the results, because PathWave is built on Keysight's expertise to ensure consistency, accuracy and measurement integrity.

HOW IS PATHWAVE OPEN, SCALABLE AND PREDICTIVE?

PathWave is open for integration with third-party hardware and software, allowing you to quickly connect compatible hardware to speed test workflows. The open APIs enable simplified and rapid customization, allowing you to connect and integrate all design and test resources.

PathWave offers a modular software architecture that scales to your requirements. It can be deployed on a desktop or in the cloud, offering scalable computing power to meet varying workloads. It provides a common user interface, accelerating programming across multiple test resources.

PathWave performs advanced data analytics to drive improvement and efficiency. It provides powerful analysis tools to mine data sets, determine patterns and predict future outcomes and trends. It also delivers a global, 360-degree view of operations and asset management. PathWave improves productivity and asset utilization with built-in predictive algorithms.

PathWave is the industry's first software platform integrating design, test, measurement and analysis. It offers a wide range of plug-ins and applications built on a common architecture and framework. It is available in a variety of configurations for specific users, such as design or test engineers. You can build specific solutions by selecting the appropriate plug-ins and integrating application-specific content. Built using open, scalable and predictive principles, the platform can be enhanced by you.

Here are three examples of what can be found on the PathWave platform:

PathWave Test

Ensure your test software never slows you down. Keysight PathWave Test provides a portfolio of powerful measurement, test automation and data management tools. From simple test plans to complex distributed enterprise systems, PathWave Test provides seamless data access, ensuring interoperability at any point in the workflow. Leveraging Keysight's trusted algorithms, PathWave Test assures your design, analysis and test results will be consistent throughout the product life cycle (see ***Figure 1***).

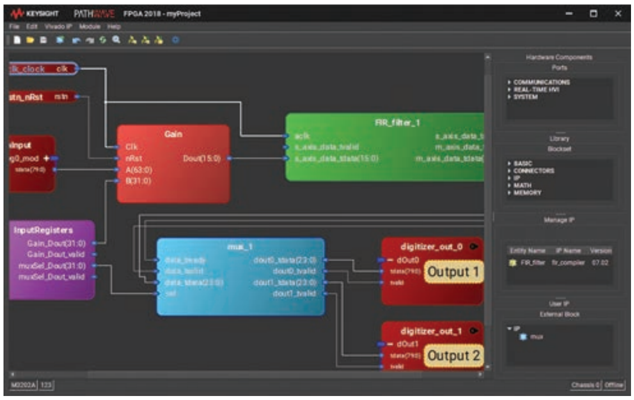

Fig. 3 PathWave FPGA is a system-level FPGA development environment that creates, deploys and simulates custom hardware acceleration directly in Keysight instruments.

PathWave Analytics

All instruments can fail. You, as a manufacturing engineer, know it is your job to identify and fix failures as soon as possible. Would it not be better to predict failures with a high level of confidence? Keysight PathWave Analytics is an Industry 4.0 solution, allowing you greater insight into your data. It is platform agnostic and comes with built-in predictive and automated anomaly-detection algorithms, to alert you when your instrument is about to fail or outliers are detected. You can perform real-time data analysis to increase productivity and asset utilization on your manufacturing line (see ***Figure 2***).

PathWave FPGA

Today, prototyping is accelerated using modular instruments with open FPGAs. Inserting custom logic into these FPGAs using Keysight PathWave FPGA cuts weeks off prototyping spins. The logic, running more closely coupled with the signal path, provides a powerful "hardware in the loop" method to accelerate test time and provide more realistic results. Tests can be optimized to customer specifications, with custom protocols and generation and detection algorithms, filters, DSP blocks and other processes. Schematically-oriented FPGA design tools automatically compile down to the FPGAs in Keysight instruments with little or no FPGA programming experience needed (see ***Figure 3***).

PATHWAVE ACCELERATES YOUR WORKFLOW

PathWave offers a set of integrated software products for your entire design, test and verification workflow. These products are connected, interoperable and rapidly reconfigurable, delivering the industry's most integrated software platform and enabling you to allocate the right computing resources, evaluate collected data, predict bottlenecks and rapidly correct issues to ensure the most efficient workflow. Adopting Keysight PathWave is a partnership between you and Keysight that accelerates your workflow.

Keysight Technologies Inc.
Santa Rosa, Calif.
www.keysight.com/find/PathWave

All-in-One RF Test System

Elite RF
Hoffman Estates, Ill.

A compact and cost-effective alternative to bulky and expensive test equipment has been the dream of many an engineer. Elite RF, a Chicagoland designer and manufacturer of power amplifiers and systems, tasked its engineers to develop a multi-purpose RF test equipment product that would be a workhorse for the RF engineer. The goals were to be as versatile as possible, have a small footprint—yet remain affordable compared to the typical RF test equipment on the market. The S-Series product line is the result of that development.

Fig. 1 Testing a 900 MHz, 65 W power amplifier.

TEST BENCH IN A BOX

The S-Series is a general-purpose, all-inclusive RF test bench in one enclosure, a product that can be used for R&D characterization on the bench, EMC assessment and automated production test in the factory. The SPA1241 comprises a 12.4 GHz spectrum analyzer, 12.4 GHz RF tracking generator, 13.6 GHz dual signal generator, 18 GHz RF power amplifier, 200 MHz four-channel oscilloscope and 10 GHz RF power meter—in one piece of equipment. The RF equipment built into the S-Series can be used stand-alone or with other external equipment.

All of the instruments are accessible through front-panel connectors, except for the oscilloscope, which is accessed from the rear panel. Instrument settings are controlled with a wireless keyboard and mouse, which are provided with the instrument. The unit has Ethernet, USB and Wi-Fi interfaces and an HDMI connector on the rear, to connect an external monitor, which allows viewing multiple instrument displays at the same time. The Ethernet and Wi-Fi interfaces enable connection to the internet to access data sheets, test specifications and other documents during testing.

Fig. 2 M-series 500 to 2500 MHz, 25 W power amplifier.

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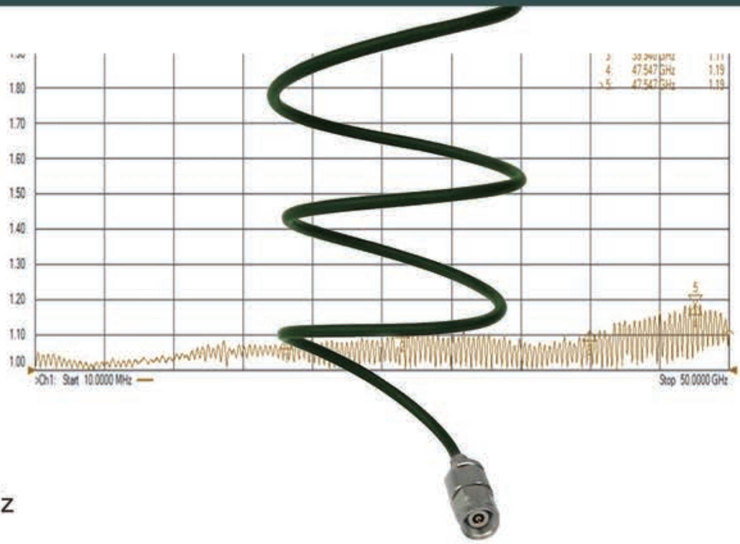
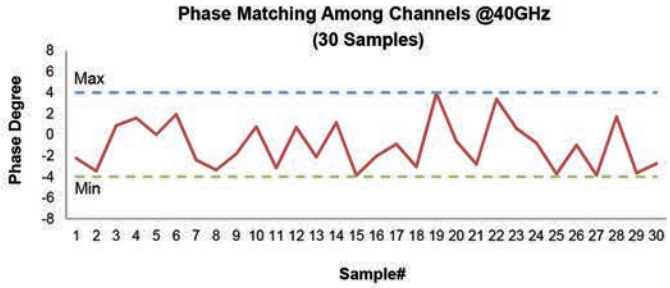
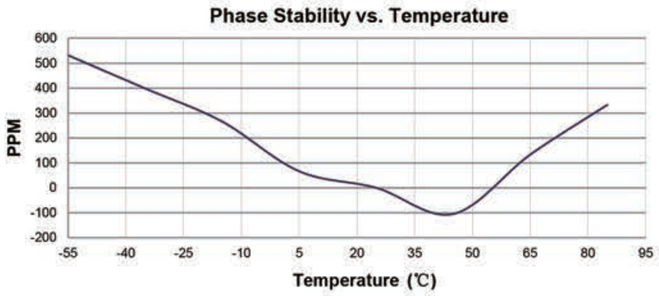
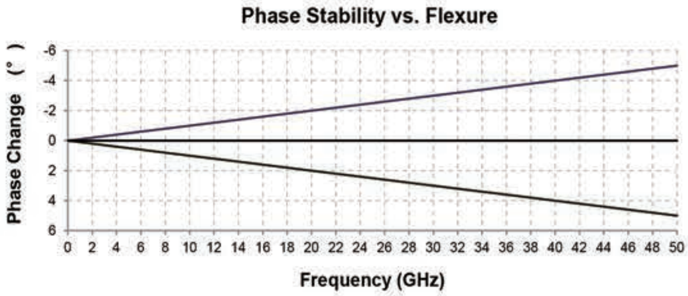


Applications:

- Massive MIMO connecting & testing
- Lab & production testing
- In-box connection
- Equipment/Rack connection







Part Number	Frequency (GHz)	VSWR (Typ.)	Connector A (Male)	Connect B (Male)	Unit Price (EXW， 1~24pcs)
C29F-39-39-1M	50	1.25	2.4mm	2.4mm	$145 / pc
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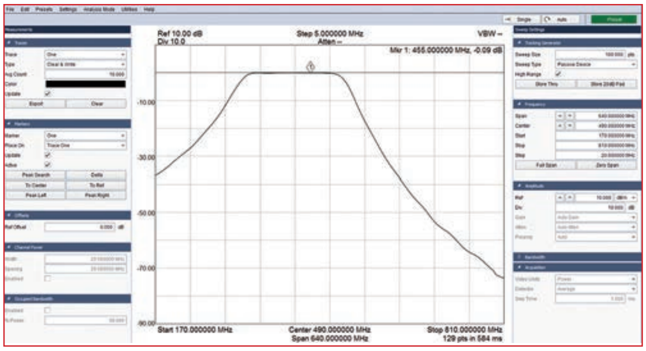
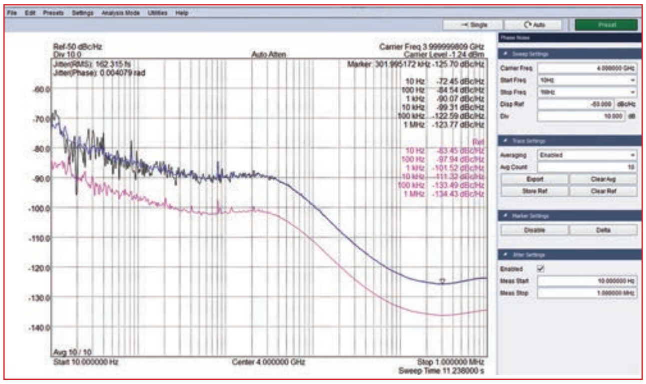
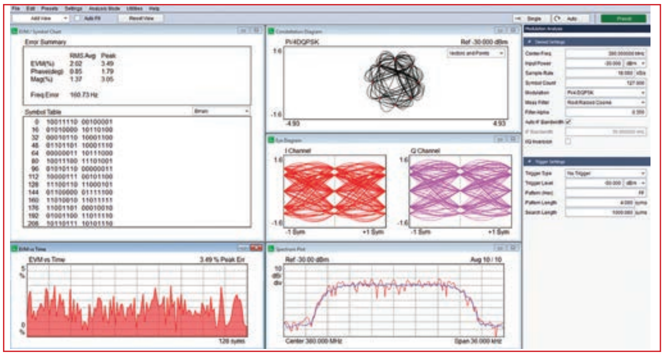


▲ Fig. 3 Scalar measurement of a bandpass filter.



▲ Fig. 4 Phase noise measurements of a signal generator at 1 and 4 GHz carriers.



▲ Fig. 5 Demodulating a digital communications signal using the spectrum analyzer as a vector signal analyzer.

The system software, built on a general-purpose PC platform running Windows 10, allows independent control of the instruments. Each instrument has a unique software application that runs on the PC and can work with other software on the PC. As one example, a Labview test program developed for the system, block or circuit being tested can automatically control the internal instruments to provide a unique RF test environment. The Labview environment can be viewed and controlled using the monitor (internal or external), keyboard and mouse.

Power for the instruments and integrated power amplifiers (depending on the model) is provided from modular power supplies and a centralized power distribution circuit board. The power supplies are compatible with 100 to 240 VAC power lines.

CAPABLE AND FLEXIBLE

A few examples illustrate the versatility of Elite RF's S-Series to test, measure and analyze:

Power Amplifiers: Power amplifier testing uses the signal generator, spectrum analyzer and power meter, as shown in ***Figure 1***. The measurement setup only requires the S-Series product and a power supply and external pads for the amplifier being tested. In this example, the harmonic performance of the amplifier, which is putting out 10 W at 915 MHz, is measured with the spectrum analyzer. While all the measurement windows—signal generator, power meter and spectrum analyzer—are open and tiled on the external monitor, the display can be configured to show only one of the instruments, such as the spectrum analyzer for a closer view of the amplifier's harmonics.

Setup and Calibration of an Amplifier: In this example, the S-Series is used to calibrate an M-Series power amplifier (see ***Figure 2***), which covers 500 to 2500 MHz and provides 25 W output power. The M-Series power amplifier can be

calibrated using the built-in functions of the S-Series. To calibrate the power and detected voltage across the frequency band, the test setup uses the signal generator and power meter with a custom program written to store the detected voltage versus power and frequency in the M-Series memory. The RF switching relay routes the RF output of the M-Series amplifier to either the S-Series power meter or spectrum analyzer. The power meter measures the output power and gain, and the spectrum analyzer measures the harmonic and spurious signal levels.

Scalar Network Analysis: The spectrum analyzer and tracking generator can be combined to create a scalar network analyzer, to measure the insertion loss of a filter, attenuator or amplifier (see ***Figure 3***). Used with a directional coupler, this test setup also measures return loss.

Phase Noise: In the phase noise measurement mode, the spectrum analyzer displays the single-sideband phase noise on a logarithmically-scaled spectrum plot (see ***Figure 4***).

Digital Demodulation: The S-Series also has the capability to demodulate a digitally-modulated RF signal by using the spectrum analyzer as a vector signal analyzer (VSA). Complex communications signals that cannot be described as AM or FM (see ***Figure 5***) can be characterized. The built-in software offers common VSA views, such as constellation diagrams, symbol-error charts and symbol tables and the system software demodulates ASK, BPSK, DBPSK, QPSK, DQPSK, 8PSK, D8PSK, π/4 DQPSK, OQPSK, N-FSK and 16-QAM.

Elite RF's innovative S-Series Multi-Purpose RF Test System fulfills the need for a cost-effective and compact alternative to a cluttered test bench. The S-Series, made in the U.S., is sold with a two-year warranty.

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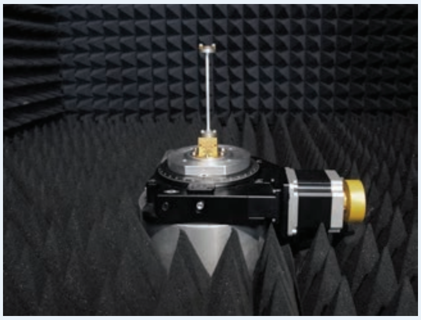

V-, E- and W-Band Rotary Joints with Dielectric Waveguides

Full-band designs for V-, E- and W-Band rotary joints—covering the frequency ranges from 50 to 75, 60 to 90 and 75 to 110 GHz, respectively—have been added to SPINNER's rotary joint portfolio, which initially covered narrowband W-Band. The new rotary joint models are BN 636281 (V-Band), BN 636282 (E-Band) and BN 636283 (W-Band).

To develop the new models, SPINNER's challenge was to provide outstanding insertion loss and VSWR performance across the full bands. The result: all three rotary joints typically have a VSWR better than 1.5 and an insertion loss below 1 dB. Another design goal was to offer excellent stability with rotation; over their full frequency bands, insertion loss variation with rotation is less than 0.2 dB, phase variation typically less than 2 degrees. SPINNER says that the three new rotary joint types are the only ones on the market that can provide this performance over their full waveguide bands.

To complement the rotary joints in high-end test applications requiring very low insertion loss, high stability and good VSWR, flexible dielectric waveguides for E-Band (BN 533659) and W-Band (BN 533660) are available in standard lengths of 30, 60 and 90 cm, and they can easily be reconfigured to custom lengths. The actual transmission line is made from a polymer plastic material. This reduces weight and results in extreme flexibility, very low transmission loss and high stability, offering a high performance alternative to a traditional flexible waveguide section or test cable. These devices are ideal for antenna test chambers, material testing and general measurement applications.

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SPINNER GmbH
Munich, Germany
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Waveguide Directional Crossguide Couplers Cover 5.85 to 33 GHz Bands

Pasternack has expanded its line of waveguide products with new directional crossguide couplers that cover the waveguide bands from 5.85 to 33 GHz: WR34, WR42, WR51, WR62, WR75, WR90, WR112 and WR137. The couplers are available in one of three configurations: 1) crossguide coupler with four waveguide ports, 2) crossguide coupler with three waveguide ports and a termination and 3) crossguide coupler with two waveguide ports, a termination and a waveguide-to-coax adapter. The waveguide-to-coax adapters can have SMA, N-type or 2.92 mm coaxial connectors.

The crossguide couplers have VSWR as low as 1.05:1 and directivity as high as 45 dB. Typical insertion loss is 0.1 dB, for minimal system loss in monitoring applications. The couplers are made with bronze or copper-alloy waveguide bodies and EIA- (CPR) or UG-style flanges, per military standards. The flanges incorporate a cross wall configuration, offering nominal mid-band coupling values of 20, 30, 40 or 50 dB. All of the crossguide couplers come preassembled with the terminations and/or waveguide-to-coax adapters. Pasternack's product line includes a selection of 160 crossguide couplers in stock and ready for same-day shipping.

These couplers serve product development and characterization applications for instrumentation and test benches. A common application is measuring power to monitor power levels with minimal signal loss to the main transmission line.

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Low Loss E- and W-Band Isolators

Micro Harmonics has released the first products in a family of mmWave isolators, targeting applications requiring low insertion loss and superior isolation. The initial products cover 60 to 90 GHz, with WR12 waveguide interfaces and 75 to 110 GHz, with WR10 interfaces. Two of the WR12 isolators have been optimized for the popular 71 to 76 and 81 to 86 GHz bands, with remarkably low insertion loss of 1 dB or less and 20 dB typical isolation. The full-band models work well outside the standard waveguide bands. Power handling exceeds the current state-of-the-art, as Micro Harmonics uses diamond substrates to channel heat to the waveguide block.

The company has also developed a drop-in isolator topology comprising a center plate, housing the core assembly and an E-plane split waveguide block, containing a stepped waveguide twist on both input and output. This topology can be used as a stand-alone component or the center plate can be removed and the core assembly integrated into a larger system. A drop-in isolator covering W-Band has a typical insertion loss of 1.4 and 25 dB isolation. To facilitate designing the drop-in isolator into the next assembly, Micro Harmonics will provide computer-aided design drawings and reimburse the customer for returning the outer housing.

Micro Harmonics was founded in 2008 as a research and design consultancy for microwave, mmWave and sub-mmWave components. The ferrite isolator technology was developed for use on NASA sub-millimeter missions, supported with Small Business Innovation Research (SBIR) funding. Based on the technology, the company is developing a line of Faraday rotation isolators and circulators in the waveguide bands from 50 to 320 GHz. Commercial uses include scientific instrumentation such as plasma diagnostics, chemical spectroscopy, biomaterial analysis and radio astronomy.

Micro Harmonics
Fincastle, Va.
www.microharmonics.com

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www.exoduscomm.com

New Corporate Website Unveiled

Accessible across all digital devices, desktop and mobile, Exxelia's new website has been revamped to offer an enhanced user experience with an ergonomic design, a parametric search engine and high-quality technical information. It features user-friendly design, improved functionalities and enhanced rich content to assist electronic engineers, component purchasers, industry professionals and students to quickly access information. Exxelia's vast product portfolio is easier to browse and more than 680 product series are listed on the website with relevant literature accessible for each series: datasheets, 3D models, high-res pictures and more.

Exxelia

www.exxelia.com

IMST Webshop Update

The new webshop of IMST not only has a new design, but also convinces with a more user-friendly interface. In addition to Wireless M-Bus, LoRa® and RADAR products, software and seminars are also offered. International shipping, as well as fast and competent purchase advice complements the comprehensive range of the IMST products and services.

IMST GmbH

www.shop.imst.de

Added Mobile Device Support

K&L Microwave's website provides information and tools to speed the identification and specification of custom design solutions from the full range of company products. The latest update features mobile device support and introduction of the AB series of printed bandpass filters on the Filter Wizard® design tool. K&L is part of the Microwave Products Group, a premier global supplier of mission/system-critical engineered electronic components and subsystems. Research capabilities, access data sheets, submit quote requests and download catalog sections. Visit www.klmicrowave.com today.

K&L Microwave

www.klmicrowave.com

Relaunched Website with Added Features

Marki Microwave has relaunched their website with a fresh look and exciting new features and tools. Pricing is now shown for all products in all configurations, including volume discounts. Product photos are also provided for all configuration options. There is an extensive RF and microwave learning center complete with application notes, technical articles, videos, calculators and AWR/ADS models. To stay current with the latest innovations in high performance broadband MMIC design bookmark markimicrowave.com today.

Marki Microwave

www.markimicrowave.com

Enhanced Design Tools

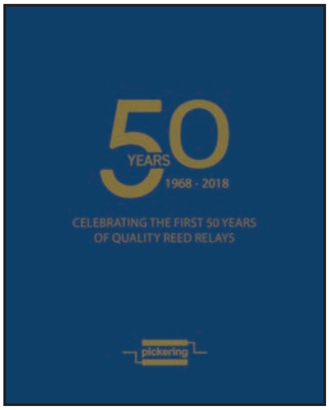
Microwave Journal has published an enhanced online Design Tools section with a compilation of free tools, software, calculators, spreadsheets and more that RF and microwave engineers can utilize or download. A description, graphic and link are available for each tool for quick reference. The library includes offerings from leading RF/microwave companies such as Analog Devices, Pasternack, NI/AWR, Keysight, CST, ANSYS, Sonnet, Comsol, MathWorks, Remcom, Custom MMIC, Mician, Rogers, K&L, Coilcraft and more.

Microwave Journal

www.mwjournal.com/designtools

Web&VideoUpdate

Pickering Celebrates 50 Years

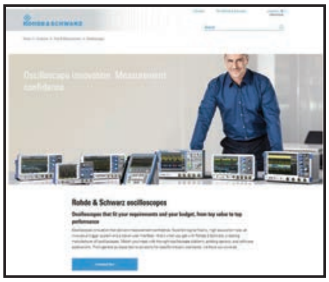


To celebrate 50 years in business, Pickering Electronics has various celebrations planned, including publishing a book on their website about the company's first 50 years of manufacturing quality Reed Relays. The book features various milestones in Pickering's history, along with stories, quotes and personal photographs from their founder, directors and employees. The book is now available to download for free from the Pickering Electronics' website.

Pickering Electronics
www.pickeringrelay.com/pdfs/50-Years-of-Pickering-Electronics-Book.pdf

Relaunch of Oscilloscope Website

VENDORVIEW

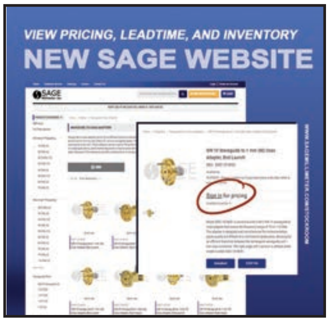


The new Rohde & Schwarz oscilloscope website offers a state-of-the-art user experience. Find the oscilloscope that fits your requirements and your budget, from top value to top performance. Match your need with the right oscilloscope platform, probing options and software applications. The website features many new functions, including pricing, a clear feature list, comparison of up to three products with a single click and a sort function in the product lists.

Rohde & Schwarz GmbH & Co. KG
www.rohde-schwarz.com/oscilloscopes

Updated Products Website

VENDORVIEW



SAGE Millimeter launched a new website in September 2017, providing comprehensive information about the company's extensive catalog of mmWave products, which range from components to test equipment, 18 to 170 GHz. Datasheets featuring specifications, plotted performance and outline drawings are available. Customers who register an account on the website are also granted access to view pricing and place orders. The platform allows delivery for in-stock items to be accommodated within three business days.

SAGE Millimeter
www.sagemillimeter.com

10 Facts in 90 Seconds Video

VENDORVIEW

Need state-of-the-art digitizers or arbitrary waveform generators? Want a solution that exactly fits your needs without compromising your specifications? The new video from Spectrum Instrumentation explains why the company is the solution provider of choice for people wanting a perfect fit solution. Over 28 years, world famous research institutions and multinational companies have come to rely on Spectrum products. Check out "10 Facts in 90 Seconds" on Spectrum's home page at www.spectrum-instrumentation.com.

Spectrum Instrumentation
www.spectrum-instrumentation.com

2.2-5 Calibration Kit Available

VENDORVIEW

New applications such as small cells, MIMO and DAS are driving the development of even more compact network equipment and smaller connectors to support the further miniaturization of antennas and RRUs. The new 2.2-5 connector system is derived from 4.3-10 and delivers the same excellent electrical performance while only being half the size. It is now well on its way to being standardized, and SPINNER has already launched the first high-precision calibration kit for it.

SPINNER GmbH
www.spinner-group.com

Enhanced Website for North American Customers

TMD has upgraded its company website to further support its growing customer base in North America. The improved website allows customers to download technical data sheets and product-specific capability brochures. TMD's evolving product line-up of microwave power modules (MPM), travelling wave tubes (TWT), high voltage supplies and commercial amplifiers developments are posted to keep customers informed. The new TMD USA website will be updated regularly to announce company information, new product releases and relevant technical information.

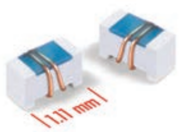
TMD Technologies LLC (TMD USA)
www.tmdus.com

NEW PRODUCTS

FOR MORE NEW PRODUCTS, VISIT WWW.MWJOURNAL.COM/BUYERSGUIDE
FEATURING VENDORVIEW STOREFRONTS

COMPONENTS

0402-Sized Ceramic Chip Inductors



Coilcraft's new 0402DC Series ceramic wirewound chip inductors offer the industry's highest Q factors in an 0402 (1005) size—up to 162 at 2.4 GHz—for super low loss in high frequency circuits. It is offered in 26 standard inductance values ranging from 3 to 120 nH. An additional 73 values are available upon request, including 0.1 nH increments from 2.8 nH to 10. Most values are available with 2 percent tolerance.

Coilcraft
www.coilcraft.com

Digitally Controlled PIN Diode Attenuator

Model A3G-69N-3JQ is a digitally controlled GaAs attenuator that operates from 50 MHz to 18 GHz. It is capable of a 32 dB attenuation range in 0.125 dB steps. The attenuation flatness is ± 1.25 dB with a 1.8:1 V.S.W.R. in 50 Ohms and a 4.75 dB insertion loss. This GaAs attenuator is digitally controlled via 8 bits of TTL compatible binary logic with a switching speed less than 1 μs.

G.T. Microwave Inc.
www.gtmicrowave.com

Shielded Surface Mount Inductors

Gowanda's ER5025S series complements MIL-PRF-39010 QPL axial-leaded (thru-hole) products and enables their conversion to SMT circuitry via this new MIL-PRF-39010 qualified SMT series. ER5025S meets QPL's ER requirements to failure rate level M (for /17 and /18). The performance ranges provided by this series include inductance from 0.10 to 10,000 μH, Q min from 40 to 60, SRF MHz min from 1 to 450, DCR Ohms max from 0.025 to 139 and current rating mA DC from 30 to 2245.

Gowanda Electronics
www.gowanda.com

Limiter

Herotek offers a new series of high-power 100 W CW limiters. Model LS00130P100A operates from 10 to 3000 MHz. It also has 1000 W peak (1 μs pulse width) power handling capability. The limiter has maximum insertion loss of 1 dB, maximum VSWR of 2:1. Its typical limiting threshold is +6 dBm, typical leakage at 1 W CW input is +14 dBm, at 10 W CW, +18 dBm and at 100 W CW, +20 dBm and is hermetically sealed for military application, and has removable connectors for MIC assembly.

Herotek Inc.
www.herotek.com

TNC Components

VENDORVIEW

MECA offers a line of BNC power dividers, attenuators and terminations. Power dividers from 2- through 16-way, 40 W power divider/combiners are optimized for excellent performance across all wireless bands from 698 MHz to 2.7 GHz. Also 2 W terminations and attenuators are available in values from 1 to 32 dB. Made in the U.S. with 36 month warranty.

MECA Electronics Inc.
www.e-MECA.com

Splitter

VENDORVIEW

The RFSP5722 splitter from MiniRF is designed for applications that require small, low cost and highly reliable surface mount components. Applications may be found in broadband, wireless and other communications systems. These units are built lead-free and RoHS compliant. S-parameters are available on request.

MiniRF
www.minirf.com

Double Balanced Mixer

VENDORVIEW

PMI Model No. DMBX-4G12G-19-8D5-SFF is a double balanced mixer operating over the

4 to 12 GHz frequency range. This unit provides a minimum isolation of 19 dB from LO to RF while maintaining a maximum noise figure of 8.5 dB. This compact mixer measures 1.000" × 0.725" × 0.510" and is outfitted with field replaceable SMA female connectors.

Planar Monolithics Industries Inc.
www.pmi-rf.com

Low PIM Terminations

VENDORVIEW

RFMW Ltd. announced design and sales support for MECA low PIM, 380 to 2700 MHz terminations. MECA's LPTC100-4310M handles

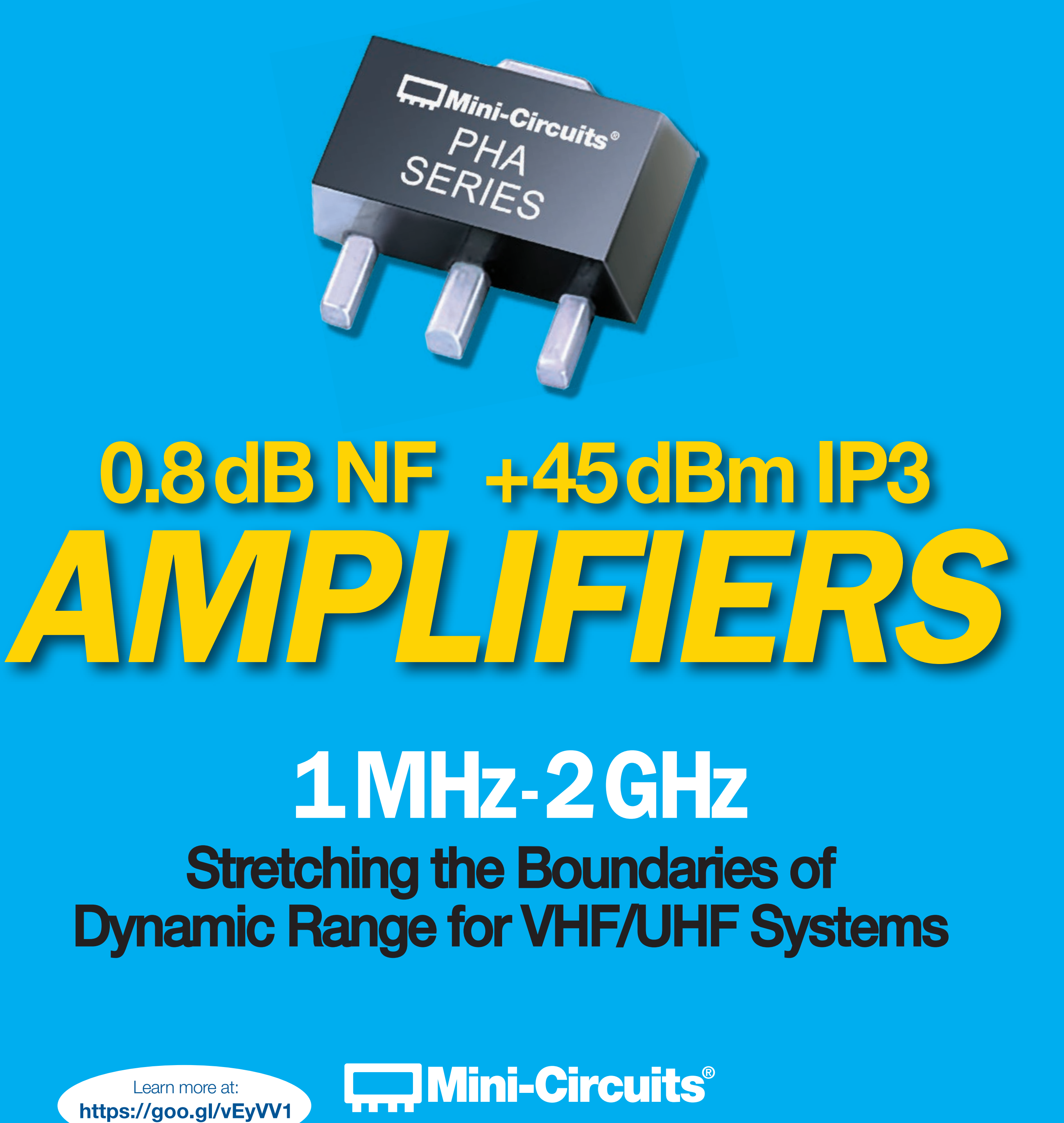
100 W with a typical PIM rating of -161 dBc. PIM is the non-linear mixing of two or more frequencies in a passive (or linear) device creating poor system performance in equipment such as distributed antenna systems (DAS). With a 4.3/10.0 DIN male connector, the LPTC100-4310M is IP 67 rated, making it a perfect choice for harsh environments.

RFMW Ltd.
www.rfmw.com

Equalizers

RLC Electronics' gain and line loss equalizers combine filter and attenuator technology to achieve a desired response to 40 GHz. The typical curves that follow are representative of commonly requested responses, including both linear and half-sine responses. VSWR is dependent on frequency of operation, complexity of equalized response and bandwidth of response. Power handling is dependent on the physical size of the absorptive elements. Since these elements decrease in size with increasing frequency, power handling by 10 GHz is usually in the hundredths of watts.

RLC Electronics Inc.
www.rlcelectronics.com


Mini-Circuits
PHA
SERIES
0.8 dB NF +45 dBm IP3
AMPLIFIERS
1 MHz - 2 GHz
Stretching the Boundaries of
Dynamic Range for VHF/UHF Systems
Learn more at:
https://goo.gl/vEyVV1
Mini-Circuits®
Rev Orig_P

New**Products**

Orthomode Transducer

VENDORVIEW

Model SAT-363-25028-C1 is a WR-28 orthomode transducer (OMT) that operates between 30 and 42 GHz. The OMT separates a circular or elliptical polarized waveform into two linear, orthogonal waveforms or combines two linear polarized waveforms into one circular or elliptical polarized waveform or vice versa. The OMT also supports either vertical or horizontal polarized waveguide forms with more than 30 dB cross polarization rejections. The OMT shows high port isolation while providing a low insertion loss.

SAGE Millimeter
www.sagemillimeter.com

Ka-Band 5 Band External or Internal Reference LNB

Spantech S.A. announced the availability of the Norsat, five band LNBs for Ka SATCOM (17.2 to 22.2 GHz). With both internal reference (9000HI5-4) and external (9000XI5- 4), it is suitable for the most demanding applications. Spantech distributes the full range of Norsat products.
Spantech S.A.
www.spantech.es

Precision Phase Shifters

Spectrum Elektrotechnik GmbH offers a line of phase stable, low VSWR, precision phase shifters, engineered for high performance military and commercial applications. The products are designed for constant impedance of 50 Ohms over the whole adjustment range. The precision mechanical mechanism guarantees continuous adjustment over the entire frequency range, and a locking mechanism ensures stability of the desired position during vibration. The newest product is the mini phase adjuster of P/N LS-0165-VFVM, covering the frequency range of DC to 65 GHz.
Spectrum Elektrotechnik GmbH
www.spectrum-et.com

0.3 to 100 MHz Power Divider

The DSK-721S is a 2-way power divider covering the frequency range of 0.3 to 100 MHz and operating over a temperature range of -55°C to 85°C. This product features an insertion loss of 0.21 dB typical and 0.4 dB maximum above the 3 dB theoretical split loss. The Isolation is 40 dB typical and 36 dB minimum, the phase unbalance is 0.2° typical and 1° maximum and amplitude unbalance is 0.01 typical and 0.15 dB maximum.
Synergy Microwave Corp.
www.synergymwave.com

CABLES & CONNECTORS

High Speed mmWave End Launch Connectors

Fairview Microwave Inc. has released a new line of high speed end launch connectors. They are ideal for signal integrity measurements, chip evaluations, coplanar waveguide, 25 GbE, SERDES, substrate characterization and test fixture applications. Fairview's new line of high speed end launch connectors is comprised of four models that provide VSWR as low as 1.10:1 and a maximum operating frequency of 40 to 110 GHz, depending on the model.
Fairview Microwave Inc.
www.fairviewmicrowave.com

V-, E- and W-Band Quick Connect Adapters

Now building waveguide systems is fast and easy. Connect and disconnect in seconds. Build systems fast and with better performance. Repeatable measurements, reduced loss, lower RF leakage. Quantum Microwave also has amplifiers, multipliers, mixers, attenuators, straights, bends and synthesizers.
Quantum Microwave
www.quantummicrowave.com

Edge Card Connectors

Samtec has expanded their line of edge card connectors with 0.8 mm and 1 mm pitch sockets designed for higher speed applications and optimal mating alignment. The 0.8 mm pitch socket (HSEC8-DP Series) is a differential pair version of Samtec's popular Edge Rate® 0.8 mm pitch sockets. Rated for speeds to 28 Gbps NRZ/56 Gbps PAM4, the socket features Edge Rate® contacts designed to increase cycle life and decrease crosstalk.
Samtec Inc.
www.samtec.com

AMPLIFIERS

Solid State Power Amplifier System

VENDORVIEW

Exodus Advanced Communications introduced the AMP4052, 32 to 40 GHz, 10 W, 40 dB, 100 to 240 VAC system. This Class AB linear state of the art solid state power amplifier features an instantaneous wideband GaAs FET design with built-in protection circuits for high-reliability and ruggedness. The AMP4052 is suitable for all single channel modulation standards. It is packaged in a 2.5 U chassis with an approximate weight of 11 kg. This system is available with a digital monitor and control upon request.
Exodus Advanced Communications
www.exoduscomm.com

2018 Asia-Pacific Microwave Conference

APMC 2018

November 6-9, 2018, Kyoto International Conference Center, Kyoto, Japan

http://www.apmc2018.org/

Harmonious World Connected by Microwaves

APMC is the largest microwave conference in the Asia-Pacific region. We are proud to announce that APMC 2018 marks the commemorable 30th conference and will be held at Kyoto, Japan on November 6-9 in 2018. Prospective authors are invited to submit original papers on their latest works. Papers presented at the conference will be submitted for inclusion into IEEE Xplore.

CONFERENCE TOPICS

- IoT
- Active Devices and Circuits
- WPT
- Systems
- Passive Components
- 5G
- Antennas and Propagation
- ITS

KYOTO

IMPORTANT DATES

Paper Submission Deadline	May 19, 2018
Notification of Acceptance	Aug. 10, 2018
Final Manuscript Upload Deadline	Aug. 31, 2018

CONFERENCE SCHEDULE

Tue, Nov. 6
Workshops/Short Courses
Welcome Reception

Wed, Nov. 7
Technical Sessions
Opening Ceremony

Thu, Nov. 8
Technical Sessions
Banquet

Fri, Nov. 9
Technical Sessions
Award/Closing Ceremony

- Student Design Competitions are also scheduled. All students are welcome to participate.
- Travel fund support program is available for students and those from developing countries.
- Sponsors (Platinum, Gold, Silver, etc.) are solicited.
- For more information, please visit http://www.apmc2018.org/

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IEICE Technical Committee on Microwaves
IEICE Technical Committee on Electronics Simulation Technology
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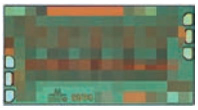
IEICE Technical Committee on Integrated Circuits and Devices
IEICE Technical Committee on Electron Devices
IEICE Technical Committee on Antennas and Propagation
IEICE Technical Committee on Wireless Power Transfer
IEICE Technical Committee on Short Range Wireless Communications
IEICE Technical Committee on Intelligent Transport Systems Technology
IEICE Technical Group on Terahertz Application Systems
Japan Institute of Electronics Packaging
Japan Society of Electromagnetic Wave Energy Applications
The Radiation Science Society of Japan
IEEJ Investigating R&D Committee on Advanced Technology for Progress the Electromagnetic Wave Application
IEEJ Investigating R&D Committee on Highly Secure-Reliable Wireless Networks

NewProducts

ADM Amplifier Series



Marki Microwave now offers their popular ADM amplifier series as bare die. ADM-5974CH provides 14 dB of gain from DC to 35 GHz with +22 dBm saturated output power. ADM-5931CH offers 11 dB of gain from DC to 28 GHz with +17 dBm saturated output power. Uniquely designed to suppress even harmonics and improve odd harmonic efficiency, these amplifiers are ideally suited as LO drivers for their patented T3 mixers and pair well with their MMIC and microlithic mixers.

Marki Microwave
www.markimicrowave.com

Ultra-Wideband Coaxial LNA

VENDORVIEW

Mini-Circuits' ZX60-153LN+ is an ultra-wideband connectorized LNA providing low noise figure of typically 2.4 dB across the entire 0.5 to 15 GHz frequency range, supporting a broad range of applications including Wi-Fi, LTE, S-Band radar, C- and X-Band SATCOM, test instrumentation and more. It delivers 17 dB typical gain with ±2.7 dB flatness, P1 dB of +16 dBm and +28 dBm IP3.

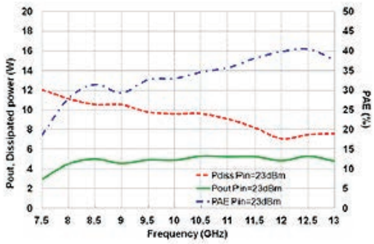
Mini-Circuits
www.minicircuits.com

Rugged Rack Mount Amplifier

Mini-Circuits' HPA-50W-63+ is a high-power rack mount amplifier capable of delivering 50 W saturated output power over the entire 700 to 6000 MHz bandwidth, supporting high-power test applications for all the primary wireless communications bands. The amplifier provides 56 dB gain with ±4 dB flatness, 97 dB reverse isolation and +50 dBm IP3. This rugged design features built-in safety features including over-temperature protection, fan alarms and immunity to open and short loads while delivering up to +45 dBm output power.

Mini-Circuits
www.minicircuits.com

GaN 5.5 W, X-Band, Medium Power Amplifier



Richardson RFPD Inc. announced the availability and full design support capabilities for a new two-stage medium power amplifier from United Monolithic Semiconductors S.A.S. (UMS). The CHA6710-99F is a GaN-based 5.5 W, X-Band medium power amplifier. It exhibits 36 percent of power added efficiency and 23.5 dB linear gain. It is manufactured using UMS' proprietary 0.25 μm gate length GaN HEMT process and is available as a bare die. The new PA is designed for a wide range of applications, including defense and commercial communication systems.

Richardson RFPD Inc.
www.richardsonrfpd.com

SYSTEMS

Fiber Optic Precision Sine Wave Transmission System

Liteway Inc. announced a new Luxlink® fiber optic transmission system specifically designed to transmit high precision 10 MHz timing related sine wave signals via interference free fiber optic cable using linear analog circuitry and internal low pass filters and can transmit signals up to 20 miles depending on the type of fiber used. Basic features are phase noise levels of -140 dbc/Hz, harmonic levels of better than -60 dB and VSWR of less than 20 dB, an MTBF of better than 100,000 hours (per MIL-HDBK-217) and are manufactured in the U.S.

Liteway, Inc.
www.luxlink.com

Customized mmWave Solutions

A new small business in Amherst, Mass. provides customized mmWave solutions by combining mmWave module expertise with interfaces, controllers and DSP to provide complete solutions for a wide range of mmWave applications including front-ends, gain-selectable amplifiers and test automation.

Millimeter Wave Systems LLC
www.millimeterwavesystems.com

SOURCES

Compact Waveguide Gunn Diode Oscillators

VENDORVIEW

Pasternack has unveiled a new line of compact waveguide Gunn diode oscillators that are tunable and generate signal levels that exhibit low phase noise at popular K- and Ka-Band frequencies. Typical applications include transmit and receive oscillators for radio communications, local oscillator source that can be multiplied for higher mmWave frequency test and measurement, military and commercial radar sources, police radar, Doppler sensors and security screening.

Pasternack
www.pasternack.com

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Connecting Minds. Exchanging Ideas.

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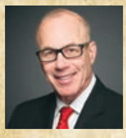
Don't miss this year's exciting keynote speakers at the Microwave Week in Philadelphia !

IMS Plenary Session Speaker (Monday, 11 June 2018):



"The Hitchhiker's Guide To the Healthcare Galaxy: The Actions That Changed the Healthcare Landscape in America From 2017-2027"

Stephen K. Klasko, MD, MBA, President and CEO, Thomas Jefferson University and Jefferson Health

IMS Closing Session Speaker (Thursday, 14 June 2018):

"Extreme Platforms for Extreme Functionality"

Nader Engheta, PhD, H. Nedwill Ramsey Professor at the University of Pennsylvania

RFIC Plenary Session Speakers (Sunday, 10 June 2018):

"Compact Silicon Integrated mmWave Circuits: From Skepticism to 5G and Beyond"

Zachary J. Lemnios, Vice President, Science, Technology & Government Programs, IBM T.J. Watson Research Center

"The Road Ahead for Autonomous Cars – What's in for RFIC"

Lars Reger, Automotive Chief Technology Officer (CTO), Business Unit Automotive, NXP Semiconductors

IMBioC Opening Session Speaker (Thursday, 14 June 2018):

"Renal Denervation for Uncontrolled Hypertension: Complexity After Symplicity"

Dr. Nicholas J. Ruggiero II, MD

IMBioC Closing Session Speaker (Friday, 15 June 2018):

"Is There a Fundamental Law of Health and Disease?"

Dr. Chung-Kang Peng, Director of the Center for Dynamical Biomarkers at Beth Israel Deaconess Medical Center / Harvard Medical School (BIDMC/HMS)

EARLY BIRD REGISTRATION ENDS 14 MAY 2018

FOR MORE INFORMATION, VISIT WWW.IMS2018.ORG

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Exhibition Dates: 12–14 June 2018 • Symposium Dates: 10–15 June 2018

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MTT-S

NewProducts

SOFTWARE

Modelithics® COMPLETE Library for Sonnet® Suites™

VENDORVIEW

Modelithics Inc. announced the newest version of the COMPLETE Library, version 17.6, for Sonnet Suites. This release adds a significant number of new models, increasing the library content by approximately 20 percent. Scalable Modelithics Microwave Global Models™ allow designers to achieve very accurate RF and microwave design simulation quickly and easily. Each model represents the complete range of part values in a vendor component family.

Modelithics Inc.
www.Modelithics.com

ANTENNAS

Standard Gain Horn Antennas

The Standard Gain Horn Antenna (SGAH) series has been upgraded in design principle, model definition, fabrication techniques and the calibration and verification method. The series is linearly polarized, lightweight and corrosion resistant, featuring high accuracy (±0.5 dB) and a reliable structure. The frequency range is 0.32 MHz to 300 GHz and typical gain values are 10, 15, 20 and 25 dB. Other gain values and horn sizes also can be designed on request. There are three input styles: waveguide, built-in coaxial and coaxial connector.

HengDa Microwave
www.hengdamw.com

MATERIALS

Epoxy Based, Dual Curing Adhesive

VENDORVIEW

Master Bond UV22DC80-10F is a single component, nanosilica filled compound featuring a UV and heat curing mechanism. This thixotropic, moderately low viscosity compound has a viscosity of 8000 to 12,000 cps at 75°F (~ 23°C). It provides outstanding dimensional stability and superior physical strength properties.

Additionally, UV22DC80-10F is optically clear and offers the ability to be cured in shadowed out areas. It is designed to cure in 10 to 30 seconds at 365 nm with 10 to 40 mW/cm^2 of UV output, followed by a post cure at 180°F (~ 80°C) for 30 to 60 minutes.

Master Bond Inc.
www.masterbond.com

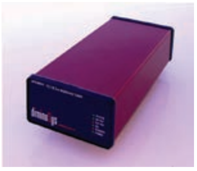
TEST & MEASUREMENT

Network Analyzers

The Ceyear AV3672 line of network analyzers are cutting edge and have an extremely competitive value proposition without compromising quality. It is offered in five different frequency ranges up to 67 GHz, both two and four port configurations, and frequency range extension up to 500 GHz. A number of measurement options such as time domain, frequency offset, gain compression, mixer measurements, embedded LO, pulse and much more are available.

Ceyear
www.topdogtest.com/ceyear

Handheld 0.5 to 18 GHz Low Noise Tuner



The compact MP518B500 wideband tuner from diminuSys spans 0.5 to 18 GHz with 500 MHz instantaneous bandwidth, fast tuning, low phase noise, control flexibility, output versatility and mobility. Overall tuner gain is adjustable from -40 to +20 dB. The MP518B500 offers input preselection with bypass mode. Its wideband output is centered at 1000 MHz with auxiliary ports at 900, 120 and 21.4 MHz. All four outputs are synchronous and without frequency inversion.

diminuSys
www.diminuSys.com

RF Pulse Profiling Power Sensor

VENDORVIEW

The LB480A is a high dynamic range RF pulse profiling power sensor that provides the user with a time domain plot of the signals pulse modulation. Internal and external triggered measurements are possible. In addition to pulse profiling measurements, the sensor can continuously make over 2,000 settled average power measurement per second making it ideal for manufacturing test applications. The sensor also makes statistical peak and pulse measurements.

LadyBug Technologies
www.ladybug-tech.com

For more new products, visit www.mwjournal.com/buyersguide

Frequency Measurement Technology

Ignacio Llamas-Garro, Marcos Tavares de Melo, Jung-Mu Kim

This unique first-of-its-kind resource provides practical coverage of the design and implementation of frequency measurement receivers, which aid in identifying unknown signals. The technologies used in frequency measurement interferometry-based on-delay lines and filters are explored in this book. Practitioners also find concrete examples of microwave photonics implementations. The designs and concepts that cover conventional photonic instantaneous frequency measurement (IFM) circuits are explained. This book provides details on new designs for microwave photonic circuits and reconfigurable frequency measurement (RFM) circuits using diodes and MicroElectroMechanical Systems (MEMS).

This book explains the many diverse applications of frequency measurement that are used in defense, radar and communications. The instrumentation used to perform frequency measurements is explained, including the use of block analysis for network and spectrum analyzers and calibration techniques. Readers learn the advantages of using frequency measurement based on RF/microwave techniques, including immunity to electromagnetic interference, low loss, compatibility with fiber signal distribution and parallel processing signals. Moreover, readers gain insight into the future of frequency measurement receivers. The book examines both the underpinnings and the implementation of frequency measurement receivers using many diverse technological platforms.

Contents: Frequency Measurement Fundamentals; Instantaneous Frequency Measurement (IFM); Reconfigurable Frequency Measurement (RFM); Photonic Instantaneous Frequency Measurement.

To order this book, contact:

Artech House
www.artechhouse.com
Email: artech@artechhouse.com
US 800-225-9977
UK +44 (0)20 70596 8750

ISBN: 978-1-63081-171-6
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£109

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Frequency Matters.

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Northeast Reg. Sales Mgr.
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Today, K&L ships more than 100,000 filters each year from four facilities filling 182,000 square feet. Three are located in Salisbury, Maryland, where K&L was born; the fourth, in the Dominican Republic, focuses on low-cost, high volume products. K&L has a Technical Assistance Agreement that allows the Dominican Republic facility to support ITAR-controlled products, important because the company's filters are widely used on radar, electronic warfare, communications and missile systems. Roughly 75 percent of K&L's business comes from defense and space programs, with the remainder from telecommunications and industrial applications. K&L has an enviable heritage in space, with filters on Apollo 17, Iridium, GPS, the Mars Science Lab and numerous other missions.

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K&L's filter products are grouped in four families: chip and wire, ceramic, cavity and multi-function assemblies, the latter integrating filters with other circuits such as amplifiers, switches and limiters. Engineering and manufacturing are organized as teams dedicated to each family, ensuring tight feedback loops between engineering and manufacturing and between assembly and test. Dedicated teams develop expertise with a filter technology, resulting in higher quality and faster time-to-market.

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D9710	8-Way	1000-2500	2,000	0.3	1.40:1	1 5/8″ EIA, N Female
D9529	8-Way	2305-2360	1,000	0.2	1.15:1	7/16 Female, N Female
D9528	8-Way	2305-2360	2,000	0.2	1.15:1	7/8″ EIA, N Female
D5320	12-Way	470-860	500	0.3	1.30:1	All N Female
D9194	16-Way	2305-2360	1,000	0.2	1.15:1	7/16 Female, SMA Female
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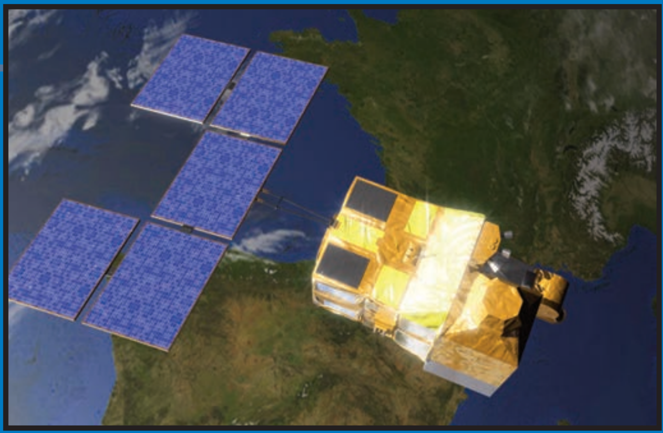

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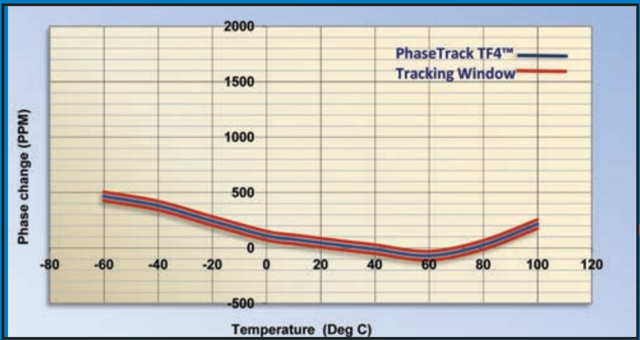

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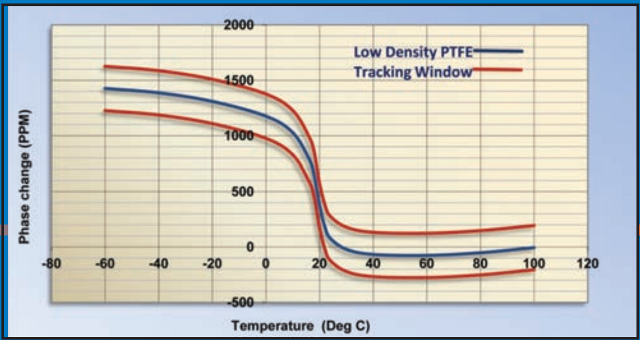

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Shielding Effectiveness of Microwave Cable Assemblies

Paul Pino
W. L. Gore & Associates Inc., Landenberg, Pa.

Shielding effectiveness of microwave cable assemblies: Why is it important? How does it impact system performance? What makes a "good shield" good and a "bad shield" bad? In this article, we will examine cable assembly construction and show an example of the shielding effectiveness of airframe cable assemblies.

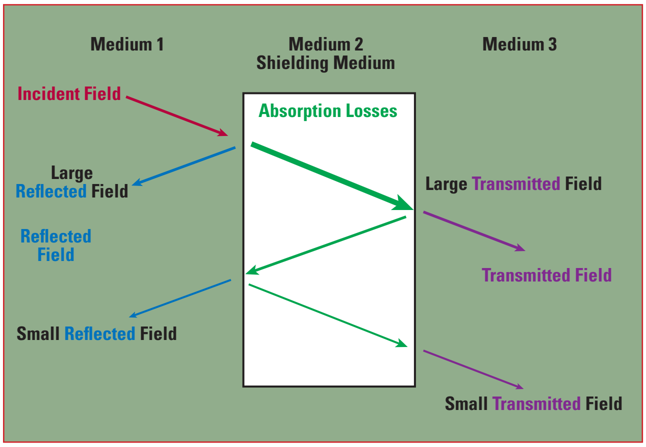


Fig. 1 Schellkunoff model of E-field shielding. Source: York EMC Services.

Before delving into shielding effectiveness, let's define the term. A shield is a conductive barrier that envelops and isolates an electrical circuit. For a microwave coaxial cable, the isolated electrical circuit is the center conductor, dielectric and outer conductor. Because of the skin effect, at microwave frequencies the return current on the outer conductor travels through a thin layer of the inner diameter of the outer conductor. This leaves the remaining portion of the outer conductor as the shield. Shielding effectiveness is defined as the ratio of the RF energy incident on one side of the shield to the RF energy transmitted to the opposite side.

Reflection and absorption are the two primary shielding mechanisms. A widely-accepted analytical representation of shielding, known as the Schellkunoff Model,[1] is illustrated in ***Figure 1***, where Medium 2 is the shield. A portion of the incident RF energy is reflected from the surface of Medium 2. The remaining portion of the energy penetrates Medium 2, and a portion of it is absorbed, with its power dissipated by the ohmic losses in the material. The remaining energy propagates through Medium 2 to Medium 3, where a portion is reflected and the remaining energy moves into Medium 3, which is the

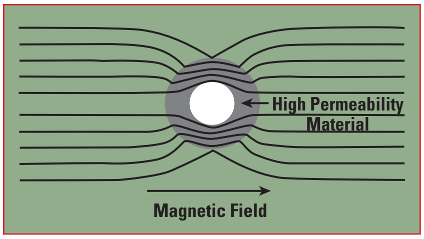


Fig. 2 Magnetic field shielding.

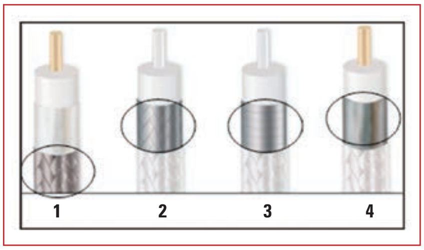


Fig. 3 Common microwave cable shield configurations. Source: Emerson Corp.

region intended to be isolated by the shield.

The majority of shield configurations only protect against E-field radiation. Magnetic field protection requires a different approach. As there is no practical means to block the magnetic field, it must be redirected around the electronic circuit by housing the circuit in a material having high magnetic permeability (see ***Figure 2***). The high permeability material, illustrated as a ring in the figure, distorts the magnetic field and isolates the center of the ring. This type of shielding is often employed when high energy, electromagnetic pulse exposure is anticipated.

SHIELD CONSTRUCTION

Microwave coaxial cable shields can take a number of forms. By far, the simplest and most effective shield is the outer conductor of a semi-rigid coaxial cable. The semi-rigid's construction employs a relatively thick, one-piece cylindrical outer conductor, formed from high conductivity material. This endows it with excellent shielding effectiveness, well in excess of 140 dB from 1 to 18 GHz.

Figure 3 shows four common shield types for flexible microwave cables. Type 1 is a braided round-wire shield, usually tin or silver-plated copper, and the most prevalent. This construction is highly flexible, easy to manufacture and serves a dual role as both a structural and electrical member. Its disadvantage is that the shielding effectiveness is directly proportional to braid coverage. With standard coverage, the typical shielding effectiveness is 40 dB through 18 GHz. Higher braid coverage will improve the shielding at the expense of cable flexibility, longer manufacturing times and increased material costs.

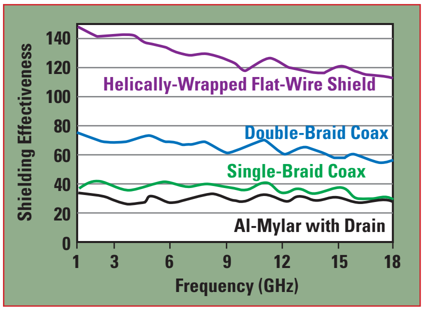


Fig. 4 Shielding effectiveness of the most common shield configurations.

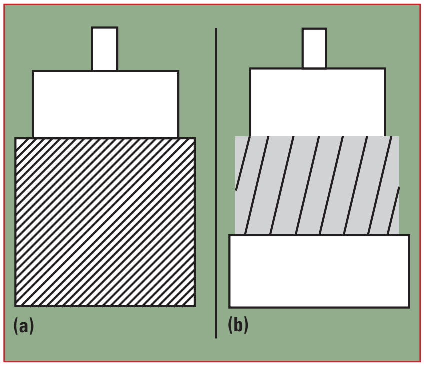


Fig. 5 Served round-wire shield (a) and served flat-wire shield (b) construction.

A braided, flat-wire shield (type 2 in Figure 3) is generally silver-plated copper. This type is structurally strong, has better shielding than type 1—typically 85 dB through 18 GHz—and the application time in manufacturing is short. However, it has higher contact resistance compared to a helically-wrapped, flat-wire shield and lower phase and amplitude stability with flexure. The helically-wrapped, flat-wire shield (type 3) improves phase and amplitude stability with flexure, reduces contact resistance, is highly flexible and can achieve a shielding effectiveness of 120 dB through 18 GHz. High quality cables use silver-plated copper flat wire. However, applying the shield is demanding, and the application process is slower than that of type 1 and 2 shields, raising the overall cost.

The fourth common shield construction (type 4) uses helically-wrapped, or "cigarette wrapped," metalized polymer foil, using Mylar®, polyimide or polyester. Polyimide offers high strength and chemical and heat resistance. Aluminum-polyester Mylar is inexpensive, light-weight and provides electrostatic discharge protection. The downside is lower performance shielding, requiring metal deposition to be conductive. The deposition process results in somewhat high contact resistance, which hurts shielding effectiveness and usually requires a "drain wire" to provide a low resistance ground path. The shielding effectiveness of the most common types of shields are compared in ***Figure 4***.

Two additional shield types are shown in ***Figure 5***: the served round-wire and served flat-wire shields. The served round-wire shield employs multiple, round-wire conductors wrapped in a spiral fashion around the dielectric. With the flat-wire version, thin, flat strips of metal, usually silver-plated copper, are spiral-wrapped about the dielectric and a layer of metalized polymer wrap is applied to bind the flat-wire bundle and reduce contact resistance. Served wire shields are used to enhance the cable's "feel," producing limp, flexible cables. Manufacturing is easy and quick, yielding low component cost. However, both types are prone to contact resistance changes with flexure, movement and temperature, reducing loss stability and shielding effectiveness.

The shielding effectiveness of a flexible coaxial cable improves as the outer conductor and shield configuration approach a continuous, one-piece construction, like the outer conductor of a semi-rigid cable. This assumes the material has a reasonably good level of conductivity at microwave frequencies. Designs that incorporate openings or gaps are susceptible to interference, i.e., receiving and radiating electromagnetic energy.

SHIELDING EFFECTIVENESS

Having discussed shielding types, we will examine the real world performance of microwave airframe cables. This particular cable type represents a unique subset of microwave cable technology, where the environment is the unpressurized portion of military combat and transport aircraft, and the cable assembly is generally used in radar and electronic warfare systems. These systems play a key role in threat detection, targeting, self-protection, communications and navigation; if the cables fail or malfunction, they risk equipment and, more importantly, lives. Because they reside in unpressurized environments, airframe cable assemblies must use a

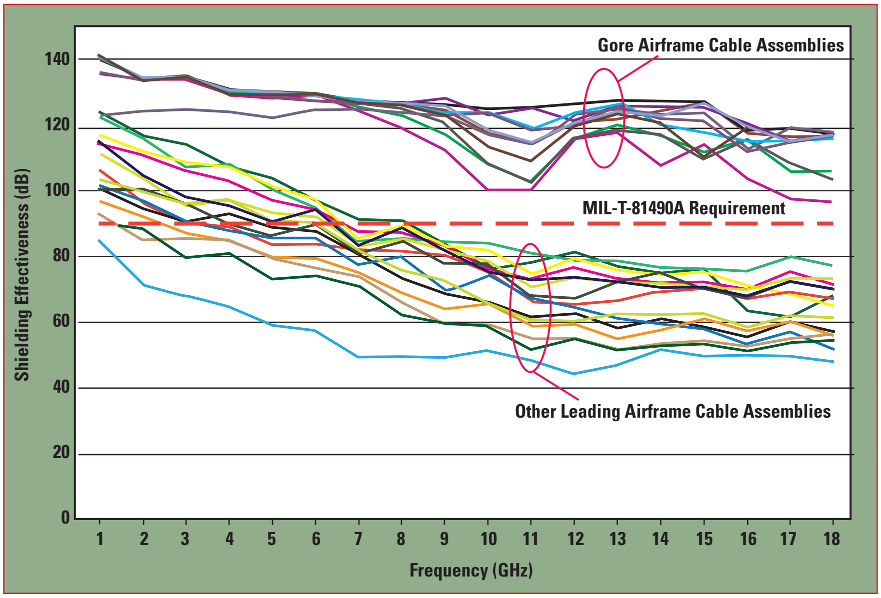


Fig. 6 Shielding effectiveness of microwave airframe cable assembly families from two companies. The minimum specification per MIL-T-81490A (AS) is 90 dB.

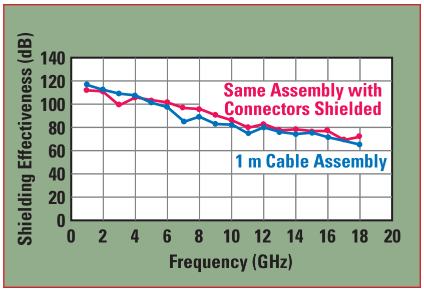


Fig. 7 Applying supplemental shielding to the connectors improves the shielding effectiveness of a 1 m cable assembly.

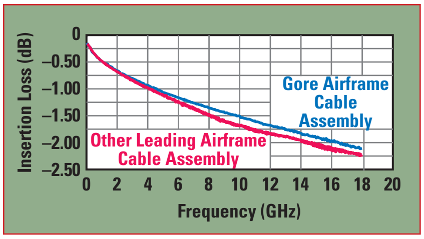


Fig. 8 Insertion loss of served flat-wire cable assembly vs. Gore helically-wrapped, flat-wire assembly.

sealed construction. If conventional, unsealed cables are used, moisture-laden air will penetrate the cable's dielectric with altitude-induced pressure changes, causing variation in electrical performance.

Microwave airframe cables used in U.S. military aircraft must comply with the MIL-T-81490A (AS) standard, which stipulates a shielding effectiveness of no less than 90 dB over the cable assembly's design frequency range. ***Figure 6*** compares the shielding effectiveness of two companies' microwave airframe cable assemblies, showing various models and assembly lengths and all rated to 18 GHz. Testing was conducted from 1 to 18 GHz per MIL-STD-1344, method 3008.

Why such a difference between the two sets of products? Connectors, connector termination and the cable are the three potential areas of RF leakage. To illustrate, ***Figure 7*** shows the shielding performance of a 1 m microwave airframe cable assembly and the improvement when the connectors and connector termination area is covered with supplemental shielding material: adhesive-backed copper foil, 0.07 mm thick × 25 mm wide. Overlapping wraps of material were used to cover the area. With additional shielding, the trace still has the same general downward slope vs. frequency; however, the performance improves notably from 6 to 12 GHz.

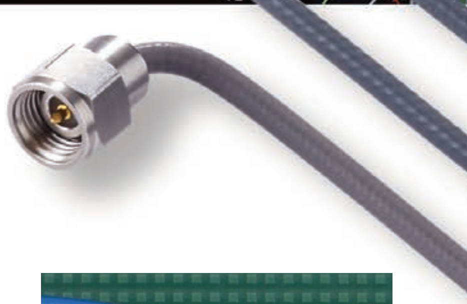
The poorer shielding effectiveness of the standard cable assembly from 6 to 12 GHz is significant enough to increase the insertion loss over the same frequency range (see ***Figure 8***), as the "dip" in shielding effectiveness represents radiated power which never reaches the end of the cable assembly. The energy is radiated outside of the cable.

Referring to Figure 7, note that the additional shielding applied to the connector area improved the 6 to 12 GHz dip yet did not affect the downward slope of the curve, which is likely an artifact of the cable's 3-mil-thick, served flat-wire outer conductor construction (see Figure 5b), wrapped overall with a thin, metalized, polymer tape. The served flat-wire configuration has continuous helical gaps running the entire length of the cable between each served flat-wire segment. These gaps are openings in the shield that act as electromagnetic radiators. To somewhat remedy this situation, a thin, metalized, polymer tape is applied over the serve, to cover the gaps and improve conductivity between each adjacent flat-wire segment. Because the primary shielding mechanism at low frequency is reflection, this works reasonably well at low frequencies. At higher frequencies, the primary shielding mechanism transitions to absorption, which is a function of the product $\sigma_r\mu_r$, where σ_r is the material's conductivity relative to copper and μ_r is the material's magnetic permeability relative to copper.[2] The polymer tape's conductivity and magnetic permeability are low compared to copper, and the tape itself is not in intimate contact with the flat wire, which further increases shield resistance. The thinness of the tape, on the order of 1.5 mils, compounds this, as well as the shielding effectiveness being directly related to shield thickness. The result of this construction, shown in the lower curves of Figure 6, is a constant reduction in shielding effectiveness above 1 GHz, falling below the MIL-T-81490A (AS) standard around 7 GHz.

The shielding performance of Gore's cable assemblies in Figure 6 is relatively flat and well above the 90 dB limit through 18 GHz. This performance can be attributed to the connector design, connector termination techniques and cable construction. The cable assembly uses a durable, helically-wrapped, flat-wire outer conductor; the flat-wire is silver-plated copper, with a thickness of 3 mils. The helical wrap ensures excellent mechanical and electrical contact between the overlapping wraps. The high conductivity of silver-over-copper provides good reflectivity at low frequencies, and the shield's overall thickness with the overlapping wraps results in excellent absorption at high frequencies.

CONCLUSION

This article addressed the shielding effectiveness of cable assemblies to provide users with a better understanding of construction techniques



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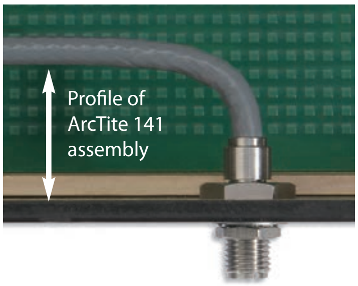

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and how they impact microwave cable assembly performance, using airframe assemblies as an example. The shielding effectiveness of microwave cable assemblies is often ignored, since adequate performance is assumed and rarely verified.

When selecting a microwave cable assembly for airframe use, ask the supplier:

- Has the cable been expressly designed for airframe applications?
- Can it withstand the rigors of airframe installation without the RF performance being compromised?
- Will it meet military shielding effectiveness standards before and after installation?

Microwave airframe cable is a crucial component of many military systems and can shape system performance. Because of this, cable selection should be given careful and thoughtful consideration.■

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THE OUTSIZED ROLE OF CABLE ASSEMBLIES

An anechoic chamber creates a free-space environment by suppressing the reflection of electromagnetic energy, achieved by lining the chamber floor, walls and ceiling with electromagnetic absorbent materials. The Benefield anechoic chamber, operated by the U.S. Air Force, is the world's largest, measuring 264 ft x 250 ft and 70 ft (see ***Figure 1s***)—big enough to house virtually any aircraft (see ***Figure 2s***). The nearly ideal free-space environment is used to test electronic warfare, radar and other electronic systems with defined routines in a controlled environment, simulating actual flight scenarios.

During testing, the aircraft is irradiated with RF energy to stress the EW system to its design limits. The facility's test equipment transmits signals into the chamber and the aircraft's EW system monitors and records the data; modern EW systems can independently track and record the system's responses. Once testing is completed, the facility provides a comprehensive data package to the customer. The data package allows the customer to assess how their system responded to various threat stimuli during the simulation.

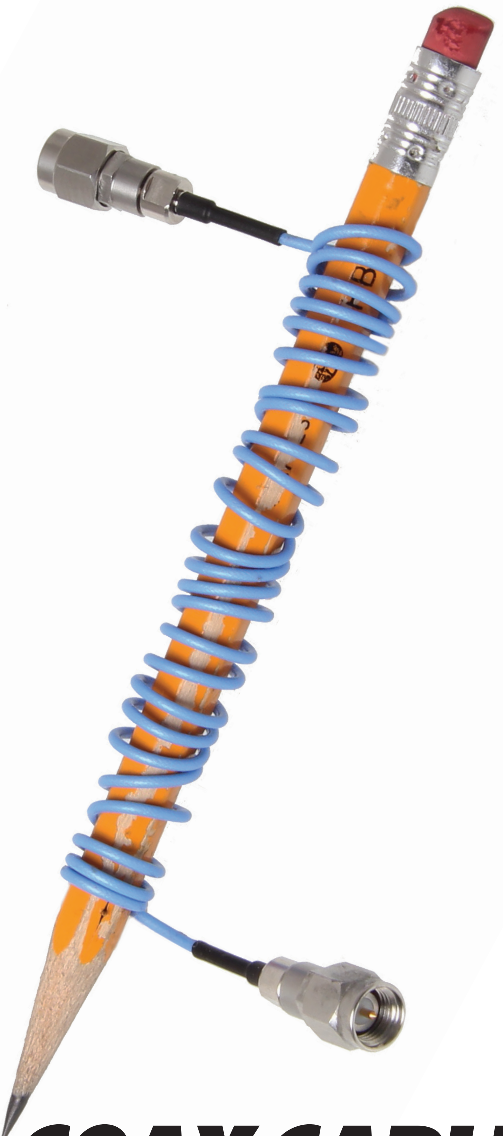
In the real world, engagement times are very short, and it is difficult and costly to fly controlled and repeatable scenarios. Assume an engagement where an enemy fighter launches a subsonic air-to-air missile against a friendly fighter. At the time the missile is launched, the two aircraft are four miles apart, converging at a closing speed of 1,200 mph. Optimistically, the friendly EW system has less than 12 seconds to identify the threat, alert the pilot and initiate countermeasures. The effectiveness and reliability of the fighter's radar, EW and communications systems is clearly crucial to the pilot's survival.

Asked what system performance problems consistently surface during testing at Benefield, facility personnel answered, "shielding issues with coaxial cables and instrumentation enclosures," observing that cable assemblies are often damaged during installation. Once compromised, they are susceptible to receiving interference and becoming sources of interference. EW systems gather data from the electromagnetic environment surrounding the aircraft to determine threat types, severity, proximity and location. Poorly shielded cable assemblies or those with damaged shields can "confuse" the EW system, leading to misinterpreted data and extended processing time. EW systems are designed to detect a threat at least 2x the threat's striking distance; interference can compromise the system's ability to detect threats at this range.

Benefield staff observed that damage to microwave airframe cable assemblies is usually caused during the installation of the cable or other components near it, not during system use or maintenance. It is not enough that an airframe cable has a good shield design; the cable must withstand the rigors of installation and potential damage when adjacent components are installed in the aircraft.

▲ Fig. 1s Aerial view of the Benefield anechoic chamber.

▲ Fig. 2s Interior of the anechoic chamber with a B-52 Stratofortress staged for testing. Pyramidal objects in foreground are electromagnetic absorbers. Source: Edwards Air Force Base



INVITED PAPER

Challenges Designing 110 GHz Coax Cable Assemblies

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While waveguide has been at 110 GHz for a while, the advent of more commercial mmWave applications such as wireless back haul and automotive radar are creating the need for a flexible cable option. Whether used in conjunction with waveguide (e.g., hybrid waveguide-coax-waveguide) or standalone (e.g., a vector network analyzer (VNA) test lead or cable connection between modules), the demand for flexible cable assemblies that operate to 110 GHz is increasing.

This article discusses the technical hurdles and associated decisions to develop a high performance 110 GHz cable assembly, including the 1) cable, 2) connector, 3) test and 4) preparation and resources. These are highly interdependent variables, such that discovering the cause of a problem during development is a combination of science and experience.

CABLE

The flexible cable size chosen for the design is a 0.055 in. (1.4 mm) outside diameter (OD) with jacket, which is a standard size within the industry with an upper frequency above 110 GHz (W-Band). There are other sizes, mostly smaller, that can achieve these frequencies; however, more connector choices are available for the 0.055 in. OD, including 1 mm, SMPS and the proprietary variants of MM4S, G3PO and G4PO.

There are design choices and material challenges for cable construction, depending on which attributes are the primary focus. Is insertion loss more important than ruggedness? Typically, you cannot have both. If loss is important, then a microporous PTFE tape is used, which makes the cable more prone to damage with normal handling. The more rugged choice is an extruded PTFE dielectric, which has an insertion loss penalty. After careful consideration, ruggedness wins, because the target market is test and measurement, where the environment has movement, a fast pace and people are used to a more robust cable. The slightly higher loss is mitigated by the applications that typically use short lengths of cable.

The next design choice is frequency range: should the cable be broadband or one constructed strictly for E-Band (60 to 90 GHz) and W-Band (75 to 110 GHz)? Not knowing how the new E-

Band and W-Band applications will use lower frequencies, a broadband cable design is chosen.

Materials and cable constructions that work perfectly well at V-Band and below (i.e., ≤ 70 GHz) sometimes show nonlinear responses above V-Band. When this occurs, there is a diagnostic hunt to identify the problems, with many potential culprits. The factory environment—compressed air and electricity, for example—can introduce intermittent anomalies in the manufacturing process. A fault length resulting in a nonlinear electrical response can be induced either by equipment or materials. Also, a design with tape or wire overlaps can cause periodicity in the electrical performance. Variations in materials from suppliers can be frustrating: one good initial lot of raw material followed by a number of lots of flawed material make the diagnostic hunt more intuitive than scientific.

Once the cable design and construction anomalies have been identified and solved, there is the issue of the test equipment. In a "what came first, the chicken or the egg" conundrum, there is always the nagging doubt about the test setup. Are the test leads good? Is the setup that was used successfully a couple hours ago still in calibration? Someone used the VNA to test at Ka-Band and you changed it back to W-Band; is the recall calibration still valid? The luxury of the time-honored diagnostic method of swapping items when there is a performance anomaly is not an option when there is only one of everything.

CONNECTORS

Choosing the cable design, by definition, narrows the choice of qualified connectors and what connectors to offer, i.e., only those designed in-house, standard connectors offered by outside vendors or a combination. Since this is still a small, evolving market, the choice is to work with all applicable connector suppliers to have the broadest offering.

The size of the component parts and the tolerances needed—while avoiding a skewed tolerance stack-up that results in interference among the component parts—is the shorthand tale of why working at these frequencies is difficult. Depending on the cable dielectric, the wavelength at 110 GHz ranges from 0.083 to 0.100 in. (2.1 to 2.55 mm) and the tolerance of the pin contact below the reference plane is 0.002 in. (0.051 mm). What did not matter at Ka-Band is now the difference between passing and failing.

Are you pursuing a domestic customer base or a global one? If global, then make everything RoHS (Restriction of Hazardous Substances) compliant—a European Union directive—because major customers will demand it, and there is no upside to maintaining two different versions in inventory. Using RoHS solders and processes requires a higher level of assembler attention and skill. When terminating the connector, heat might be a concern with the ferrule/housing if excessive heat transfer causes the dielectric to change or grow. If the design of the connector is point-and-shoot, the length of the center conductor that is inserted into the center contact may change the response curve of the connector. Here, real-time X-ray is invaluable.

There are some common problems when designing a connector in-house or troubleshooting with a trusted outside supplier. Initially, when making the transition from simulated data provided by CST, HFSS or home-brew software to empirical data, the cable or connector will not perfectly match the model. Be prepared for many iterations of design improvement, as the empirical data informs the design software. Whether using in-house design expertise or relying on a trusted external vendor, the ability to precisely machine component parts (e.g., a ferrule or a dielectric bead) is quite useful and cuts down the development time dramatically, as shown below.

The difference in equipment (e.g., VNA and related adapters) can make a difference in the shape of insertion loss and the VSWR or return loss curves. What you see may differ from what your customer or supplier sees due to the age of the calibration, age and condition of the adapters or settings used on the VNA. The importance of listening, graciously receiving feedback, providing samples and trying to re-create a problem are opportunities to learn.

Figure 1 shows a real example of iterative design and the utility of having a precision machine shop in-house. Early in the design, it was clear that the transition from cable to connector had an impedance mismatch which severely affected performance. The time domain reflectometry (TDR) function on the network analyzer highlighted this, and the most promising design change was adjusting the dimension on one of the component parts by either 0.001 or 0.002 in. (0.025 or 0.051 mm). Having a machine shop onsite made the decision easy: make two parts. Figure 1a shows "before" and Figure 1b "after." Having two parts with one dimension being a thousandth of an inch (0.025 mm) different made the fine tuning process easy. From Figure 1a, the design had a 54 Ω inductive hump; slightly modifying a component part reduced the inductive hump to 52 Ω, as shown in Figure 1b. There is also a corresponding improvement, although less dramatic, in the capacitive dip in the connector, by 0.5 Ω. This is an example of the tuning process, as improvement leads to change, which leads to compromise, which leads to iteration. Fixing one section of the connector changes the response of another section, making design modifications a series of compromises.

While all of these problems apply to the development and testing of the 1 mm thread-on connector, there are ad-

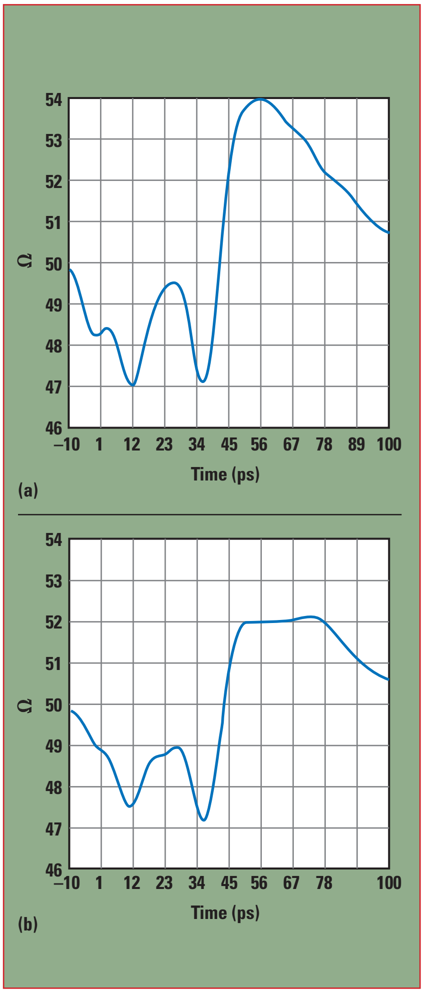

Fig. 1 TDR response of the initial connector design (a) and after tuning to reduce the inductive hump (b).

ditional perils with push-on connectors (e.g., SMPS and proprietary variants). These connectors have the theoretical capability of reaching 100 GHz into an air section, but most of the vendors have not tested them to that frequency because they do not have the equipment. This market segment is small, and the capital expense of a 110 GHz VNA cannot be justified. There are very few 1 mm to SMPS or proprietary variant adapters that are available for testing; the ones that are available are very expensive and, normally, you need two. There may not be any calibration kits for the push-on connectors. This means gating is used to get a realistic reading, which is somewhat interpretive. The concept of allowable axial and radial misalignment can lead to non-repeatable measurements.

TEST

The first hurdle with testing is the cost of the equipment and creating and approving the business case. This effort is not for the faint of heart: a VNA capable testing up to 110 GHz costs more than $400,000, the calibration kit is over $30,000 and adapters are $1,500 apiece (cheaper by the dozen). There is no way around this expense if you want to develop or manufacture E- and W-Band cable assemblies.

A VNA of this type is much like our brains; we only harness about 10 percent of the capability of the machine. While, in rare instances, some esoteric functions will be used, the same setup is normally used all the time. This means the test setup and test technician are critical to successful cable and connector development and subsequent manufacturing. Since these machines are used in various applications and organizations (e.g., universities, electronic hardware testing), your Anritsu, Keysight or Rohde & Schwarz applications engineer may not be familiar with the eccentricities of the 110 GHz coaxial cable assembly. Your test technician might provide the needed perspective to solve a problem. Allow him or her to get training from your VNA vendor, just a little bit at a time. With so many equipment functions to learn, it takes time to digest the initial training, spend time on the unit, test, make mistakes, test again and come up with the next set of questions.

Different brands of adapters perform differently, and while price is normally predictive of performance, this is not always the case. When figuring out what adapters work best in your environment, do not buy enough to hit the first price break. Buy a couple and see how they work before committing. Because of the price of the adapters, proper interface care and handling of the connectors is a must. Inspect the connector interface under magnification to insure no damage.

These are sensitive machines that are affected by temperature shifts. A 0.5°C change in temperature, which is quite normal in a loosely temperature-controlled test environment from the morning to the afternoon, can affect performance. The calibration may not last long and, if the measurements are critical, it is safer to do a new calibration. An indication of an old calibration is a nonlinear response at the frequency where the VNA extender takes the signal to 110 GHz or accelerated degradation at the upper frequency limit.

While the natural tendency for mating an SMA or 2.4 mm connector to a test lead of a VNA is to snug it twice with the torque wrench, doing that with these connectors will not improve performance and will damage the threads and internal components of the adapter. Always use a calibrated torque wrench when mating the thread-on connectors; 4 in./lb (0.45 Nm) is not much, but it is tighter than finger-tight.

Finding the source of a poor performing cable assembly is always difficult, especially with new technology. Is it the cable or connector or test setup going south—when it was fine just minutes ago? Having a gold standard that has been tested and verified for stable performance over several months is helpful in these instances.

PREPARATION AND RESOURCES

These are called the mmWave frequencies for good reason. Everything is small, tolerances are tight, equipment is sensitive, you blink and the dielectric bead has disappeared. How each company prepares the cable for terminating is specific, and each manufacturer has unique tricks. The important point for an excellent result is adherence to a set of processes that are repeatable and can

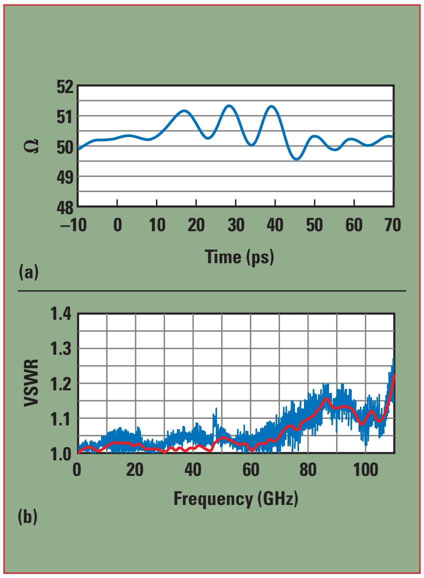

Fig. 2 TDR response (a) and VSWR (b) of the final connector design.

be audited. Whether you trim the cable using a blade, a saw or a laser, whether you tin and wick the contact, if applicable, or meter the solder, the adherence to these processes and acceptance of the processes by the manufacturing personnel is paramount.

Another paradigm shift pertains to manufacturing. Cable manufacturers are used to making L- through V-Band cables, with certain expectations for the time to manufacture and test and yields. The E- and W-Band cables are different; everything is slower by at least an order of magnitude: the time to prep and inspect the cable, terminate the connectors, identify where a problem resides (e.g., cable, connectors, termination, test setup) or when to accept failure and move on. Making this transition is easier if the manufacturing personnel are dedicated to the product rather than switching back and forth between high and low frequency cable assemblies.

SUMMARY

Compare Figure 1, which shows the connector's performance at the beginning of the development process, to ***Figure 2***, which shows the performance of the finished design, now in production. Connector discontinuities that were in the 7 Ω range, inductive to capacitive, are now in a 2 Ω range, and the VSWR confirms a cable assembly performing well to 110 GHz.

This article is a primer discussing some of the common problems encountered when designing and developing 110 GHz cable assemblies, rather than an in-depth, technical, cause-solution explanation. Users of these cables will find information to help select a supplier and some shortcuts to diagnose problems. The discussion highlights some of the reasons why a 110 GHz cable assembly that looks identical to a Ka-Band cable assembly and whose SMPS connector looks very similar to the SMPM connector, costs 3 to 5× more than the Ka-Band cable assembly.

The 110 GHz cable assembly market is growing and, as more commercial systems become available, demand will rise. After the initial use in automotive radar and wireless backhaul, there is interest in other communications services, including the soon-to-be launching satellite constellations such as OneWeb and Telesat. ■


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Coaxial Cable Assemblies Adapt to Emerging mmWave Applications

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In previous years, mmWave frequencies were used for niche military, aerospace, SATCOM and scientific research. This has changed, however, as emerging 5G, 60 GHz Wi-Fi, automotive radar and high speed data applications, operating in the tens to hundreds of GHz, are becoming common. The diversity of applications and the demand for higher frequency test systems are driving coaxial cable assemblies to the next level. These performance parameters for test cables extend beyond laboratory performance to address features specific to the new applications. From extremely tight tolerance for pristine laboratory conditions to rugged reliability for automated test facilities, the next generation of precision coaxial test cables operating at mmWave faces a wide range of "stiff" performance requirements.

Recent years have seen a rise in the use of the RF spectrum beyond 6 GHz (see ***Figure 1***). Previously, the typical applications that ventured into mmWave frequencies were military, aerospace, SATCOM, weather and research science. These applications often used waveguide interconnects and, where necessary, could support the high costs and low volume of customized mmWave coaxial cables and connectors. Now, precision mmWave coaxial assemblies are in demand for a plethora of markets and applications. Some of the new markets include photonic and mmWave integrated circuits, 5G telecommunications, 60 GHz Wi-Fi, automotive radar, high speed data, military radar and mmWave imaging. Many of the new applications, especially 5G and SATCOM antenna arrays, require large numbers of coaxial assemblies for testing and operation, and some applications require these coaxial assemblies to operate under conditions considered extreme for interconnects usually designated as laboratory equipment. The latest demands are changing the performance and feature requirements for mmWave coaxial cable assemblies.

EMERGING APPLICATIONS

5G and 60 GHz Wi-Fi

Data consumption for mobile wireless users has been dramatically increasing. The latest generation of wireless standards is designed to meet the growing need for throughput, low latency, massive connections and flexibility to emerging needs. Necessarily, the frequencies for next-generation wireless communications must extend beyond the highly cluttered sub-6 GHz block, leading the FCC and other governments

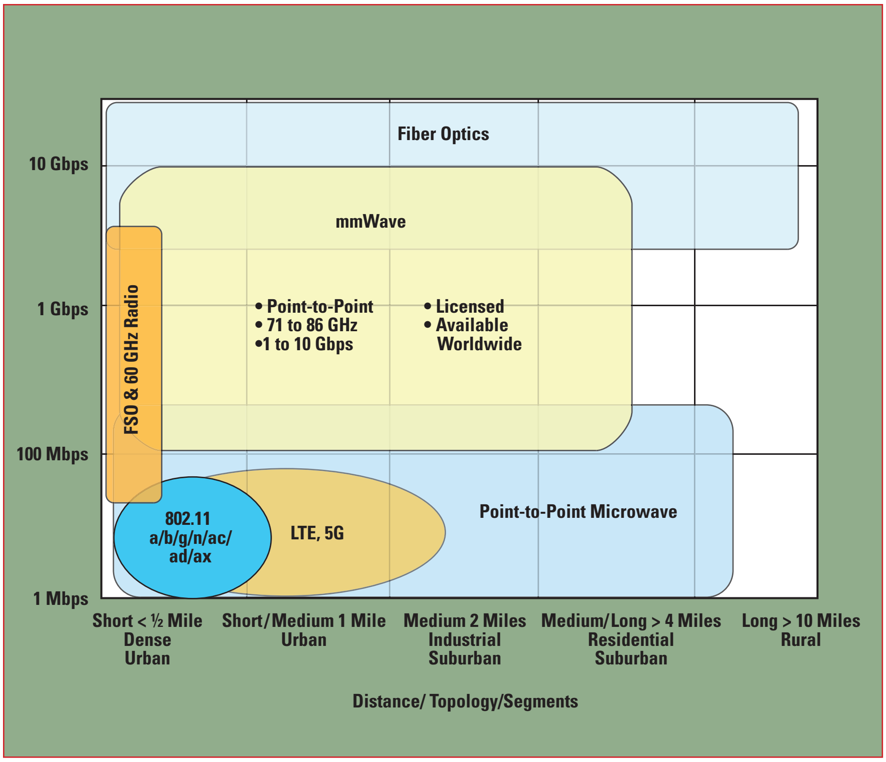


Fig. 1 mmWave applications extend from close proximity and high throughput device-to-device communications to last-mile broadband internet to the home. Source: Adapted from dailywireless.org.

to set aside substantial mmWave spectrum for 5G, 60 GHz Wi-Fi (IEEE 802.11ad) and other emerging applications. The FCC's defined frequency bands occupy 11 GHz of spectrum from 27.5 to 28.35, 37 to 38.6, 38.6 to 40 and 64 to 71 GHz.[1] Opening spectrum to develop mmWave communication networks will enable more than high throughput device-to-device and base station-to-device connections—also last-mile residential services.

The implications of consumer, industrial, military, aerospace and SATCOM technology operating in the mmWave spectrum mean there is a greater chance for electromagnetic interference, either unintentionally or, possibly, by a malicious party. To design 5G networks and 60 GHz Wi-Fi systems to operate with the tight tolerances dictated by these upcoming standards, manufacturers, system designers and technicians need access to precision and cost-effective mmWave coaxial cables and connectors, with more features and accessibility than is currently available.

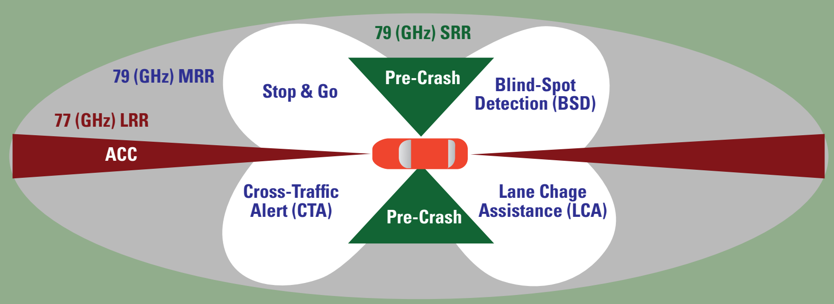
Automotive Radar and Wireless Communications

Future connected and autonomous cars will be equipped with a wide array of communications and sensors. One of the most significant applications is radar for vehicle detection, cruise control and obstacle avoidance (see ***Figure 2***). All of the automotive radar frequency bands are in the mmWave spectrum, at 24, 77 and 79 GHz. It is likely that manufacturers will not require many mmWave coaxial cables and connectors within the radar assemblies themselves, but the design, testing, installation and maintenance of these systems will require metrology-grade coaxial cables and connectors.

The next generation of cars will also be equipped with wireless communications as standalone features or augmenting user equipment as 5G hotspots. 5G machine-to-machine (M2M) communications will likely account for enhanced autonomous vehicle coordination and also vehicle-to-infrastructure (V2I) communications. All of these applications will require mmWave coaxial cables and connectors within the modules and to facilitate communications between modules.

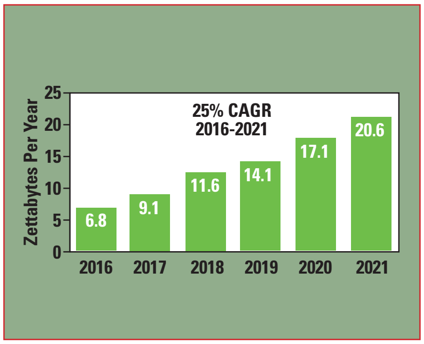
mmWave ICs

The above applications and other SATCOM, aerospace and military applications require MMICs operating at mmWave frequencies. These MMICs and the complex modules housing them necessitate rigorous testing, calibration and validation before being employed in mission-critical applications. Some of these applications, such as mmWave imaging, radar and chip-to-chip communications, may operate well above 100 GHz and require 1 mm and smaller coaxial connectors. Currently,

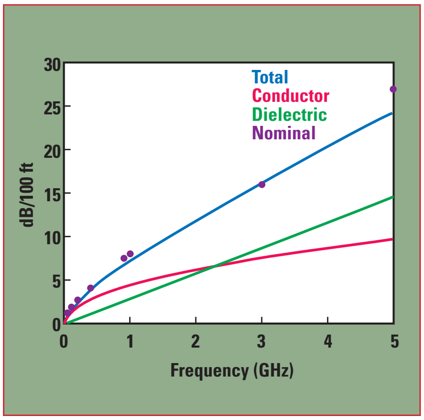


Radar Type	Long-Range	Medium-Range	Short-Range
Frequency Band (GHz)	76 to 77	77 to 81	77 to 81
Bandwidth (GHz)	0.6	0.6	4
Range (m)	10 to 250	1 to 100	0.15 to 30
Distance Accuracy (m)	0.1	0.1	0.02

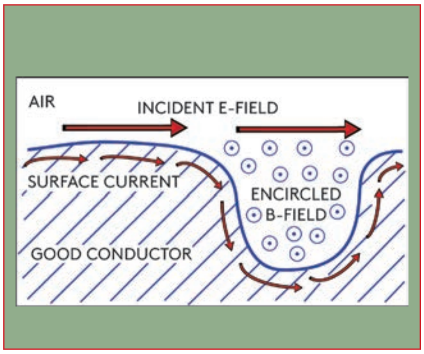
Fig. 2 Future cars will have several automotive radar systems operating at mmWave frequencies. Source: Robert Heath.[2]



▲ Fig. 3 Cisco predicts global data center traffic will exceed 20 zettabytes per year in 2021.[3]



▲ Fig. 4 The attenuation of a coaxial transmission line increases with frequency because of the increased conductor resistance and dielectric losses. RG-8/U and RG-213/U example.[4]



▲ Fig. 5 Uneven conductor surfaces leads to increased surface conductance compared to smooth surfaces.

0.8 mm coaxial cables are capable of performing to 145 GHz.

Testing systems that operate above a few tens of GHz will produce harmonics into the hundreds of GHz. For testing of power amplifiers, receivers, transceivers, mixers and modulation, mmWave testing at multiples of the base frequency is necessary to characterize performance. Hence, the future may require coaxial cable assemblies that operate to frequencies well above the range of currently available assemblies.

Automated Testing

To keep costs low, many mmWave devices will use automated testing in facilities that demand rugged, reliable, consistent and high performance interconnects. Traditional mmWave coaxial cables and connectors for test and measurement have been precision cables, which are not particularly rugged nor do they perform well under stress and strain. Automated test systems are often subject to vibration, shock, repeated flexure and many mate-unmate cycles, which many mmWave connectors will not withstand and maintain consistent performance and calibration. More rugged, metrology-grade coaxial assemblies will be needed in much higher volume, at prices and availability more accessible than available today.

High Speed Data

It is no secret that data speeds for military, government and communications systems are increasing to meet the demands of new applications and provide inter-system communication. The current transition for high speed internet traffic is from 40G to 100G Ethernet, and 400G and 800G are in experimental and demonstration platforms. The massive increase in throughput capability for communication channels is based on a need to send more data, faster and less expensively (see ***Figure 3***).

Also, digital integration into traditional, RF-only systems is increasing, to enable advanced phased arrays, massive MIMO, complex beamforming, upgraded modulation and low-probability-of-detection/low-probability-of-intercept radar. Architectures such as full-digital beamforming, software-defined radio (SDR) and cognitive radio will require much higher speed digital communications between subsystems and modules, while meeting military standards for reliability and precision. Though fiber-optic technologies are used extensively for Ethernet, there are still requirements for short runs, design/prototyping, installation and maintenance, which will require the use of mmWave coaxial assemblies.

mmWave Coaxial Cable and Connector Sourcing

These emerging applications will require coaxial cables and connectors in much higher volume and lower cost, without sacrificing performance, than historically provided by the industry. Shorter design cycles and competitive time-to-market will require low lead time sourcing of mmWave coaxial cables and connectors. It is likely that many current manufacturers do not stock what has previously been a niche item, and rapid availability of mmWave coaxial assemblies will be attractive to users in a much wider range of markets than before.

mmWAVE CONSIDERATIONS

The reasons mmWave coaxial cables and connectors are expensive and behave differently than lower frequency coaxial systems are because of their physical, construction and material characteristics. Several frequency-dependent phenomenon drive these constraints: conductivity and skin effect, the transverse electromagnetic mode (TEM) of the coaxial transmission line, dielectric constant, propagation velocity and wavelength. The frequency-dependent conductivity of conductors and dielectric losses of coaxial transmission lines appear as a resistive loss (i.e., insertion loss) versus the frequency of the signals propagating along the line (see ***Figure 4***).

The skin depth at mmWave frequencies is a fraction of the loss at sub-6 GHz frequencies, as the skin depth shrinks with increasing frequency. At mmWave frequencies, the distribution of electromagnetic energy traveling through a transmission line will be less than 1 μm from the surface of the conductor. For example, at 6 GHz, the skin depth for copper is 0.842 μm; at 60 GHz, the skin depth is 0.266 μm.[5,6] As skin depth is a function of resistivity, magnetic permeability and frequency, materials with higher resistivity and lower magnetic permeability allow for much better transmission of mmWave signals, such as gold, silver and aluminum. These materials are more attractive to use with mmWave coaxial assemblies, leading to increased cost and more complex manufacturing and repair processes.

Another effect of skin effect and TEM transmission is that surface conditions of the conductor and distribution of the dielectric within the transmission line become important factors at higher frequencies. Poorer material and surface consistency leads to greater losses and reflections/VSWR (see ***Figure 5***). For test cables and connectors that undergo repeated reposition, flex-

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ure, vibration, shock and other forms of stress, the materials and construction methods must avoid degradation to avoid significant changes in performance.

To achieve the desired coaxial behavior, the dimensions and tolerances of the inner conductor, outer conductor and dielectric are much smaller than with lower frequency coaxial transmission lines. Smaller coaxial dimensions mean less conductor surface area and greater resistive losses and heat build-up under load. Hence, mmWave coaxial cables typically have much lower power handling and peak RF voltage, limiting usable length. Additionally, conductor and dielectric behavior depends on the temperature, humidity and other environmental factors, further limiting the materials and construction techniques viable for mmWave coaxial assemblies.

Connection repeatability for mmWave testing that involves large groups is a concern, as the tolerance of connectors are extremely tight. At mmWave frequencies, 2.92, 1.85, 1 and 0.8 mm coaxial connectors have center pins less than 1 mm in diameter. These small dimensions make these connectors susceptible to performance deviation from contaminates, oils and wear—not to mention being more fragile than larger connector sizes. Maintaining phase stability, given that small mechanical variations can dramatically change the electrical response, means that care must be taken in handling the cables and connectors. Because of these factors, field testing and troubleshooting of mmWave systems will be extremely challenging, making it difficult for technicians to use coaxial cable assemblies designed for laboratory use.

NEW FEATURES

The emerging mmWave applications and attendant considerations for coaxial cables are driving innovation in the design and manufacturing of next-generation coaxial assemblies. Some of these innovations involve adopting coaxial cable manufacturing methods and techniques from SATCOM, aerospace and military applications. Other enhancements are designed to improve ease-of-use, increase longevity and allow for more standard solutions, rather than expensive custom designs.

For example, common metals used in precision mmWave connectors include passivated stainless steel and beryllium copper plated with both nickel and gold, where the last plating step is gold. The beryllium copper provides dimensional stability over temperature, the nickel is a necessary layer to enable gold plating and the gold surface conductor provides high surface quality with good conductivity and better corrosion resistance than copper, aluminum or silver. A passivated stainless steel coupling nut and outer body provide a durable connector body with improved mate-demate cycles and corrosion resistance (see ***Figure 6***).

▲ Fig. 6 New high-performance mmWave coaxial cable assemblies use military-grade manufacturing techniques and armoring to ensure reliable performance from the laboratory to the field.

Cable armoring for mmWave vector network analyzer (VNA) test cables is also a new technique, adapted from military and aerospace applications. A coaxial test cable designed to operate to 110 GHz is roughly 0.25 in. diameter, with very thin layers of conductors and dielectric. As the coaxial structure of these cables can easily be damaged, even when carefully handled and in laboratory conditions, cable armor improves durability. Methods include additional foil and braided metal layers and light armoring with rugged synthetics such as Nomex®, crush members, external ruggedized metal armor and additional inner jackets. Though these methods of cable protection increase the size and weight of a coaxial cable assembly, they improve the rigidity of a cable while maintaining its flexibility. Where rigid and semi-rigid coaxial cable must be formed to the exact dimensions of the end application and cannot be reformed without damaging the cables, flexible coaxial assemblies with armoring can undergo repeated flexure, often with better phase and amplitude stability than un-armored coaxial assemblies.

These design techniques can improve the performance of mmWave coaxial cable assemblies and extend lifespan compared to other flexible coaxial assembly designs. These techniques do increase the cost of the assembly and often require longer lead times to manufacture. As the model for using mmWave coaxial cables and connectors changes to meet emerging trends and applications, the method of sourcing the coaxial assemblies also needs to change.

SUMMARY

Military, aerospace and SATCOM technologies and emerging applications from new markets are changing the way mmWave coaxial cables and connectors are designed, sourced and employed. Beyond precision VNA testing and use in aerospace communications and radar, mmWave coaxial cable assemblies are now being used in commercial telecommunications and automotive applications. Coaxial cable manufacturers have made strides in recent years to meet these new needs and, by some suppliers, to provide these solutions faster and more seamlessly than in the past. As the 5G, automotive radar, mmWave MMIC, automated testing and high speed data markets continue to grow, so will the need for lower cost, faster lead time and higher performing coaxial cables and connectors.

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Accurate VNA Measurements Start with Quality Cables

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Vector network analyzers (VNA) provide some of the highest accuracy measurements of any RF instrument. However, poor-quality or defective test-port cables can significantly degrade measurement accuracy and represent a leading cause of VNA measurement problems. Using a VNA with poor-quality test-port cables is like pairing a quality audio receiver with cheap speakers—the speakers severely limit the sound quality. If you start with the most accurate VNA in the world and use poor-quality cables to connect to the device being tested, your measurement results will not be accurate.

RF cables are used for most RF instruments, such as spectrum analyzers and signal generators. However, not all RF cables are suitable for VNA measurements. VNA users often grab whatever RF cable is lying around, not knowing the quality of the cable or they use semi-rigid or conformable coax cables because they are cheap and readily available. While semi-rigid or conformable coax cables work well at the beginning, they break down quickly with repeated use, as they are designed to be connected once and left in place. Conformable cables lose phase stability with just a few flexes, because the cable-connector interfaces are not reinforced at the junction, and the connector interface wears out after a few connections. At times, VNA users rely on the user calibration to make up for low-quality cables and adapters. While cable loss, phase and match are systematic errors, correctable with a calibration, any changes to these parameters behave like drift errors, which are not correctable. Any movement or reconnection after user calibration can introduce errors, reducing calibration stability and resulting in erroneous measurements.

If a cable is bad, the measurements most likely will be wrong. In manufacturing, this results in a good product being rejected or, even worse, a bad product passing. When designing an RF component, incorrect S-parameter data can lead to a costly design mistake. When impedance matching using the Smith chart, phase errors cause wasted time or may even reduce product performance, such as the transmission range of a wireless device. The potential technical problems from poor-quality cables include:

- Magnitude and phase errors in both reflection and transmission measurements, due to the phase drift of a cable, most often seen as ripples in the reflection and transmission magnitude
- Unstable or non-repeatable measurements
- Mechanical damage to the product or VNA port from damaged or worn out cable connectors.

For more insight into potential measurement errors introduced by cabling, we conducted an $|S_{11}|$ measurement on good and bad cables using a USB-based VNA. ***Figure 1*** compares a good a cable (a) with a bad cable (b). The purple trace shows the measurement when the cable is straight, the yellow trace when the cable is bent. Bad cables show a larger change in the magnitude and phase when bent. A good cable has low reflections and minimal variation when bent.

CHOOSING A GOOD CABLE

With an appreciation of how poor cabling and connectors can impact VNA measurements, how do you ensure using the right cables? Start by selecting good cables, following these guidelines:

Insertion loss and phase stability: Good test-port cables should be stable with tempera-

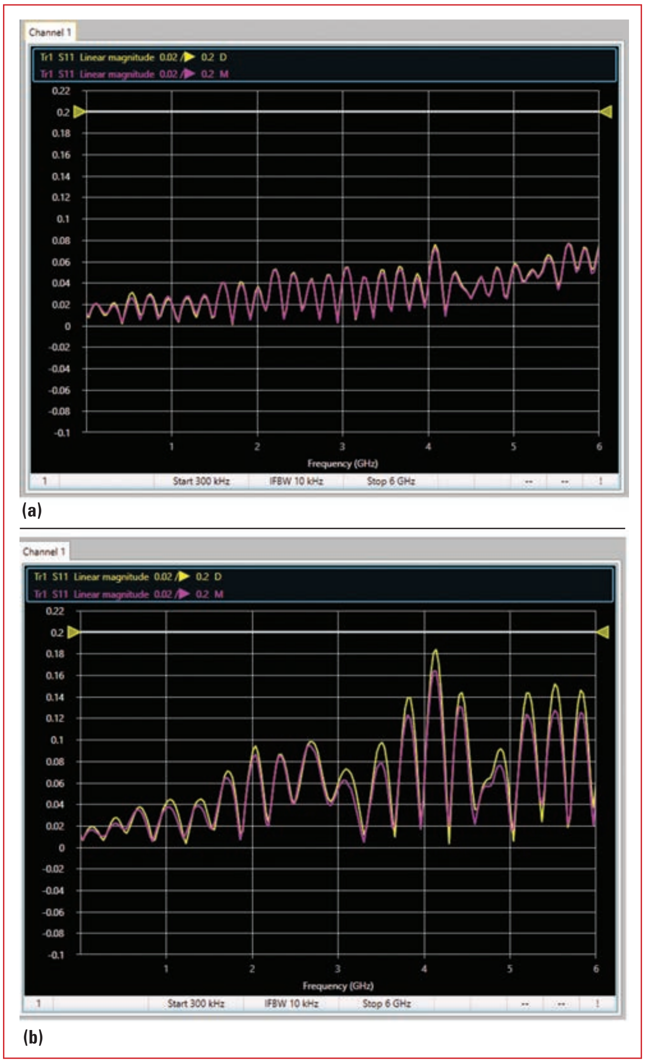


Fig. 1 $|S_{11}|$ of a good (a) and bad (b) cable, straight (purple) and bent (yellow).

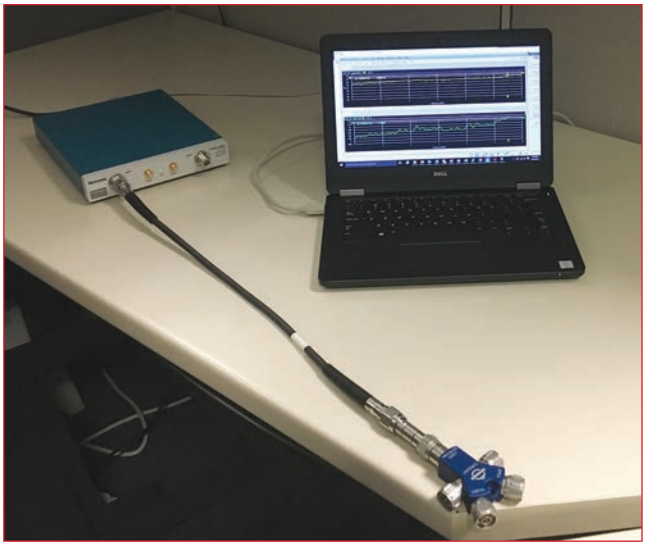


Fig. 2 Measuring the cable's return loss using a known load.

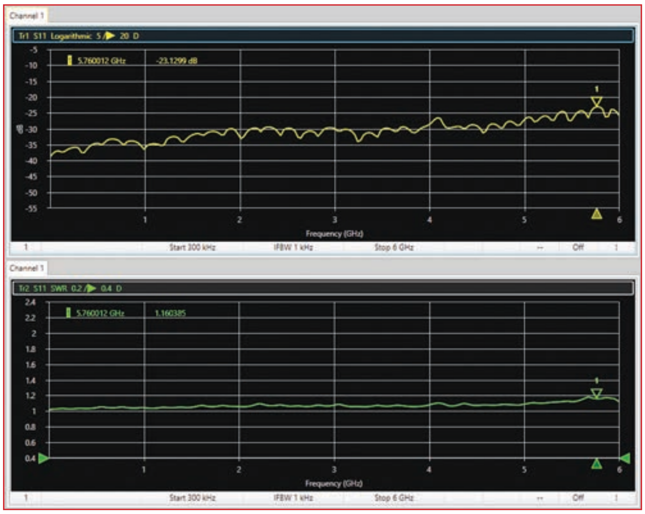


Fig. 3 Checking cable quality by measuring return loss and SWR using a VNA.

ture and when flexed or bent. Of course, the cable should never be bent beyond its minimum recommended bend radius. A good cable will typically have an insertion loss less than 2 dB across its entire frequency range, and the phase stability will be on the order of ±1 to 2 degrees.

Reinforced junctions: Bending cables to calibrate or connect to the product being tested puts strain on the interface between the cable and the connector. The cable can be damaged if this interface is not sufficiently reinforced.

Connection repeatability: The measurement should be repeatable when connecting to a device multiple times; repeatability is dominated by the quality of the connector on the cable.

Shielding: Good shielding is essential, especially if the measurements are in a noisy RF environment where electromagnetic interference and electrical noise can affect the signals.

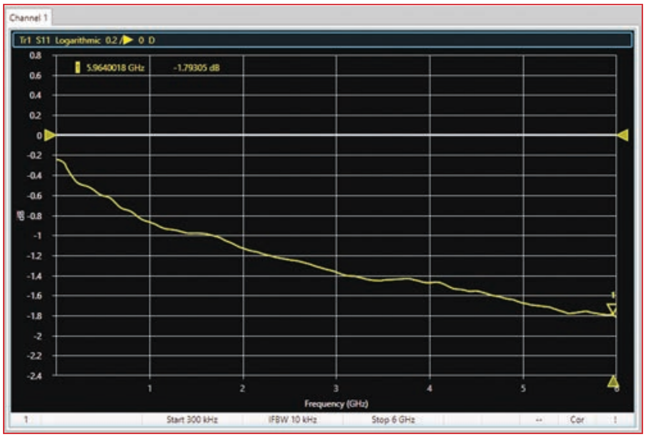
Rugged jacket: Cables used in hostile environments, where they may be bent beyond the minimum recommended bend radius or dragged through a conduit, for example, should have a rugged jacket.

Return loss or match stability: While the return loss of the test-port cable is correctable with a user calibration, the accuracy of the correction degrades as the return loss of the cable approaches 0 dB. A return loss of 15 dB or greater should be sufficient for most applications. The stability of the return loss, however, is of paramount importance. Even small changes cause large errors if the return loss magnitude or phase changes as the cable is bent between calibration and measurement.

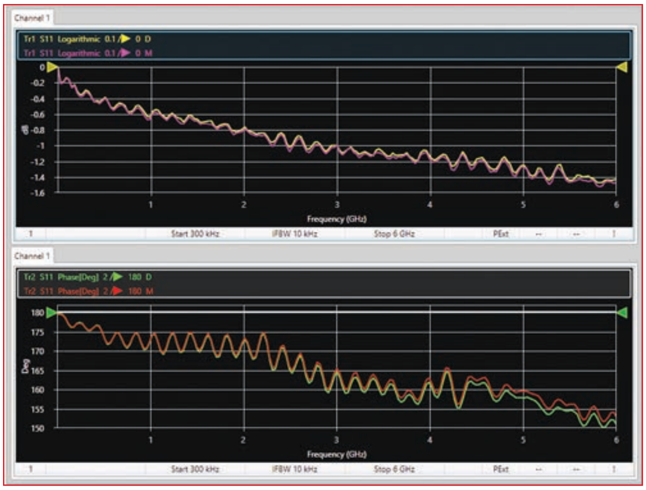
VERIFYING CABLES AND ADAPTERS

You may not always be the person buying the cables and adapters. Before making VNA measurements with whatever is available, the better course of action is to run the following simple tests to evaluate the cable and adapter quality:

SOL cal: Prior to measurements, perform a short-open-load (SOL) calibration on one of the ports of the VNA. A single port VNA is sufficient. To achieve accurate results, choose a low IF bandwidth and set the port power level to at least 0 dBm. Trace smoothing may be needed to reduce the trace noise to see small changes in the cable. In each case, adjust the reference level to center the trace on the VNA's display and adjust the scale so the trace is somewhere between 25 and 75 percent of full scale. Depending on the VNA, the



▲ Fig. 4 Determining the insertion loss of a cable by measuring the $|S_{11}|$ with the cable shorted.



▲ Fig. 5 Using a shorted cable assembly and the VNA's data-to-memory capability, changes in the magnitude and phase of a cable can be measured as the cable is flexed.

marker search function can help locate the worst-case point for each measurement.

Visual inspection: Before running any test, visually check to see if the cable or the connectors on any adapters are damaged or contaminated by dust or other particles. Even the slightest damage to the center pin can cause measurement errors or, worse, damage other components while attempting to connect to them. One way to clean the connectors is with a lint-free cotton swab dampened with isopropyl alcohol, then dried by low-pressure compressed air to clear away any remaining contaminants. You can also use a connector gage with the appropriate gender and type to measure the pin depth, comparing it with the connector's specifications.

Return loss: To check the cable return loss or SWR, connect one end of the cable to the VNA and a load to the other end (see ***Figure 2***). Ideally, display $|S_{11}|$ in dB on one trace window and SWR on another window, as shown in ***Figure 3***. Find the maximum return loss value (closest to 0 dB) and corresponding SWR and compare the measured data with the cable specifications. This measurement is only as good as the load at the end of the cable, so use a known good load with a return loss better than the expected return loss of the cable. In the example shown in Figure 3, the measured return loss is 23.1 dB (1.16:1 SWR), confirming the cable is within its specified return loss of greater than 20 dB through 7.5 GHz.

Insertion loss: To check the cable's insertion loss, with the cable still connected to the same VNA port, replace the load with a short and measure $|S_{11}|$. While a typical insertion loss measurement requires both ports of the VNA, recall that a short circuit produces a full reflection, and we can derive the cable's loss by dividing the $|S_{11}|$ magnitude in dB by two (see ***Figure 4***). This approach keeps the cable straight and does not require additional cabling. In this example, the measured $|S_{11}|$ is -1.79 dB, meaning the cable's insertion loss is approximately 0.9 dB, which is less than the cable's specification of 1.05 dB and well within the desired insertion loss of less than 2 dB.

Stability of insertion loss and return loss: The next step is to confirm the stability of the cable, which can be assessed using the same setup with the cable shorted. First, with the cable straight and not moving, store the S_{11} magnitude and phase in memory. With these traces on the display, view any changes as the cable is flexed to various positions, holding the cable steady to allow time for the VNA to complete a sweep at each position. The display will overlay the current measurement with the stored data, showing changes in the magnitude and phase (see ***Figure 5***). In the figure, the purple magnitude and red phase traces represent the straight cable, the yellow and green when the cable is bent. This cable is performing relatively well. A good cable will have low reflections ($|S_{11}|$) and minimal change when bent. Bad cables will show a larger change in magnitude and phase. To see any phase changes with high resolution, remove the electrical length of the cable. Again, since S_{11} is being measured to characterize the transmission loss and phase, the displayed results should be divided by two to get the actual loss and phase stability.

Repeatability: To check connection repeatability, keep the cable connected to the VNA, connect a broadband load in place of the short, measure the $|S_{11}|$ and store the data. Disconnect and reconnect the broadband load, repeating several times with the load rotated to different orientations. The display will show the repeatability of the connection.

Connector choices: VNA users can also minimize errors by choosing the right cable connectors for a test setup. Ideally, the connectors on test-port cables should be the "same"—but opposite gender—as the respective mating connectors on the VNA test ports and the device being tested. This avoids adapters. If adapters must be used, their contribution is mostly correctable with a user calibration; however, the extra interface is one more connection that could loosen during calibration or measurement. The adapter will also degrade the return loss of the cable, resulting in greater measurement uncertainty. As test-port cables are available with a variety of connector options, whenever possible, choose cables to eliminate or minimize the number of adapters. If they must be used, always use quality adapters.

SUMMARY

You can spend a fortune on quality cables, but you do not have to. Quality cables are available that perform well, enable accurate measurement results from the VNA and do not cost a fortune. Remember, even the best cables go bad with extended use, especially abuse. Use the above guidelines to periodically verify your cables' and adapters' insertion loss, return loss, phase stability and connection repeatability.■

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The **2801 Series** cable assemblies offer the "lowest loss in the industry" at frequencies up to 18 GHz. The cable features a multi-ply concentrically laminated dielectric of expanded PTFE, double shielding and a standard FEP jacket per ASTM D-2116. Options including LOW SMOKE/ZERO HALOGEN polyurethane jacketing and TUF-FLEX internal armoring are available for applications requiring enhanced mechanical protection. SMA, precision TNC and N Type connectors are standard for frequencies up to 18 GHz. C, SC and 7-16 connectors are also offered.

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Specifications

Impedance:	50 ohmΩ	**RF leakage, min:**	-100 dB to 18 GHz
Time delay:	1.2 ns/ft.	**Temp range:**	-65°C to +165°C
Cut off frequency:	18 GHz	**Cable outer diameter:**	0.31"
Capacitance:	24 pf/ft.	**Velocity of propagation:**	83%
Weight:	7.8 lb./100 ft.	**Flame retardant rating:**	UL94-V0

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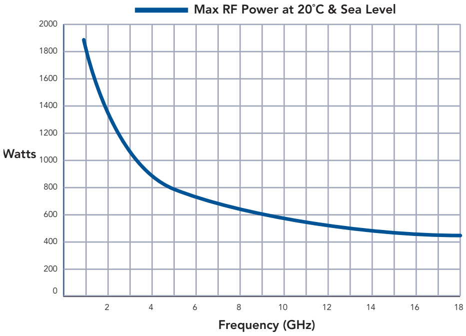
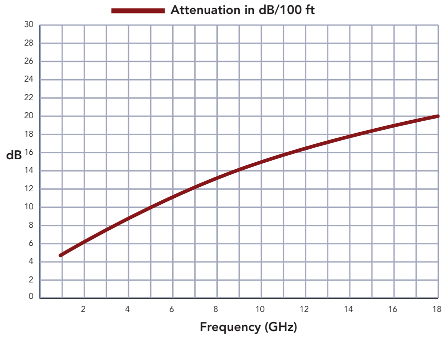
20°C at Sea Level



Attenuation in dB/100 ft



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New Connectors Expand Cable Assemblies

The standard cable assembly range from AtlanTecRF has expanded with the addition of new connector options, including SMA male straight, SMA male right angle (R/A), SMA female bulkhead, type N male straight, N male R/A and N female bulkhead. These are in addition to the standard SMA male connectors already offered across the company's cable range. These connector options can be applied to the ASR, ASF and AFX cable series.

The ASF series of reformable coaxial cable assemblies provides the microwave system designer with a versatile solution to equipment and subassembly cabling without the need for the detailed design of semi-rigids. With a copper-tin composite outer conductor, the cable can be hand formed in situ.

The ASR series of reformable coaxial cable assemblies offers a solid, tin-plated aluminum outer conductor, so the cable can also be hand formed in position, while the AFX series of flexible coaxial cable assemblies provides the designer with a versatile solution to equipment and subassembly cabling. With a braided outer conductor over a silver-plated spiral strip, the cable can be flexed repeatedly.

All cables are supplied in two different outside diameter sizes of 0.086 and 0.141 in. (nominal). They are also available in standard lengths from 2 to 60 in. Beyond the standard product range, customized assemblies are available with features including special lengths, phase matching and identification sleeves.

With this expanded range, AtlanTecRF offer greater choice, whether to help customers fulfill last minute cabling requirements or meet regular production line and prototyping needs.

VENDORVIEW

AtlanTecRF
Braintree, Essex, U.K.
www.atlantecrf.com

Low Attenuation, Phase Stable, 40 GHz Cable Assemblies

Insulated Wire (IW) has introduced what the company says are the lowest attenuation, phase stable coaxial cable assemblies operating to 40 GHz. The 157 series uses a solder-clamped 2.92 mm K connector, tailored for applications through Ka-Band, including satellite communications, probe stations and the full range of test and measurement setups.

The 157 series uses the same construction as all of IW's low loss cables: laminated EPTFE with a silver-plated copper foil and silver-plated copper braid. Cable diameters were optimized to minimize attenuation, with a maximum of 64 dB per 100 ft (2.09 dB per m) at 40 GHz. A typical 157 cable assembly with two straight 2.92 mm connectors has less than 1.1:1 VSWR, peaking around 1.2:1 above 30 GHz, versus a specification of 1.35:1. Other performance characteristics are a time delay of 1.22 ns per ft, nominal propagation velocity (Vp) of 83 percent and bend radius of 0.5 in.

Options include a solid center conductor (part number 1571) and IW's "TufFlex" ruggedized version (part number 1573). The ruggedized model has a crush resistance of approximately 175 lb per in. The outer diameter of the 1571 is 0.157 in., 0.209 in. for the 1573.

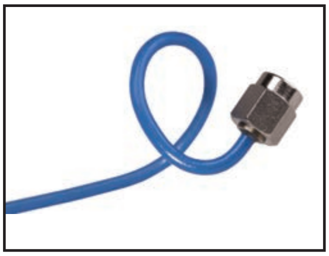
Founded in 1970, IW developed a unique PTFE lamination process and applied it to manufacturing wire and cable. Combining the lamination process with a patented shield design led IW to develop low loss microwave transmission lines using solid and expanded PTFE dielectrics.

Insulated Wire Inc.
Bayport, N.Y.
www.iw-microwave.com

DynaTest Brochure

DynaTest™ series cable assemblies are designed to deliver repeatable, precision measurements while lowering your overall total cost. These assemblies offer exceptionally low VSWR and insertion loss characteristics across a broad frequency range. This allows a single DynaTest™ cable assembly to be used for the maximum number of measurement requirements. These assemblies are highly flexible, yet maintain phase stability to ensure repeatability without the need for recalibration. DynaTest cable assemblies are available through distribution to support your standard product requirements.

Dynawave Inc.
www.dynawave.com



Phase Invariant Cable Assemblies

VENDORVIEW

HUBER+SUHNER recently launched the Minibend CTR/Mini141 CT family which combines the industry-renowned flexibility of HUBER+SUHNER Astrolab's bend-to-the-end connector termination technology with industry leading phase vs. temperature performance. Thus, it creates a stable, reliable, MILDTL-17 qualified interconnect solution to satisfy a huge range of customer applications where phase stability is key. The broad selection of available connector interfaces ensures a large variety of configurations to meet the unique requirements of our customers.

Huber+Suhner AG
www.hubersuhner.com/en/solutions/space/products/minibend-series/phase-invariant-assemblies/mini-141-ct

High Quality Cables and Connectors

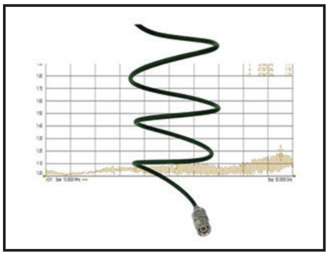
In the early 2000s, the U.K. was abandoned by the RF connector manufacturing industry. A solution quickly arrived with the launch of Intelliconnect in 2003. The U.K. company joined forces with an innovative U.S. operation and has grown into a market leader in design-led RF components. Intelliconnect manufactures many high quality cable assembly and connector ranges including Pisces waterproof connectors—the solution of choice in the defense and aerospace markets. Intelliconnect's triaxial and cryogenic components are recognized as the best in the market and the Custom Design service is the fastest in the industry.

Intelliconnect
www.intelliconnect.co.uk

MegaPhase 110 GHz Cable Assemblies

MegaPhase's 110 GHz products are offered with 1 mm connectors in both semi-rigid and flexible cable assemblies. The company's lightweight 110 GHz cable assemblies are specifically designed for the demands of high-bandwidth applications such as automotive radar, probe stations and mobile backhaul. Visit the links to review the company's data sheets for 110 GHz flexible assemblies (www.megaphase.com/rf/phase3) and 110 GHz semi-rigid assemblies (www.megaphase.com/rf/semirigid). Contact solutions@megaphase.com for a quote.

MegaPhase
www.megaphase.com



C29F High Performance Microwave Cable Assemblies

MIcable C29F (.086Flex) microwave cable assemblies offer superior electrical performance up to 50 GHz in low VSWR, low loss and phase stability. The typical VSWR is 1.25 at 50 GHz and phase stability over temperature is < 500 ppm at -40°C to +70°C. It is ideal for use in 5G MIMO connecting and testing, and regular use in lab and production line.

MIcable
www.micable.cn

Benchtop Test Solutions Product Guide

VENDORVIEW

Mini-Circuits' has innovated a line of products for these functions that are smaller, faster, easier to control and much more affordable than other options typically available in the industry. Their benchtop test and measurement modules offer the ease of control via USB or Ethernet and include programmable attenuators, power sensors, frequency counters, switch modules, signal generators and control products. Depending on the application, these units may be used as standalone solutions or easily integrated as building blocks to build scalable testing platforms customized to each user's individual needs.

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Hot New Products

VENDORVIEW

This new 20 page product guide provides a complete survey of Mini-Circuits' latest product releases from the second quarter of 2017. Highlights include everything from ultra-wideband coaxial LNAs, multi-channel programmable attenuation systems, high-power stripline 90° hybrids, ultra-wideband splitters up to 40 GHz and more. The company is continuously innovating new products to meet your needs, and this informative product line update will help you stay up to date with our latest, coolest new model releases.

Mini-Circuits
www.minicircuits.com

Test & Measurement Brochure

Rosenberger is a dependable and renowned development partner in industrial measurement technology. The product portfolio includes RF high precision connectors, adaptors and devices, PCB connections, calibration kits, microwave test cables or VNA test cables for a variety of test and measurement applications—e.g. microwave measurements and VNA calibrations, laboratory testing, factory testing, semiconductor test applications, high speed digital testing or network testing. A PDF version is available for download from the Rosenberger website or print copies can be ordered at marketing@rosenberger.com.

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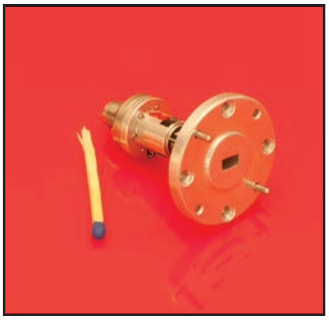

Waveguide to Coax Adapters

Spectrum's waveguide to coax adapters are designed for efficient transition between the rectangular or double ridge waveguide and one of the various coaxial connector styles. In the various waveguide bands it is decided between two mechanical configurations, top launched (right angle between waveguide and connector) and end launch (in-line). In addition it has to be decided on the application, instrumentation needing high performance, or high-reliability for space usage or high-power applications at systems. Low insertion loss and best VSWR is usually a necessity.

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